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T H E S I S

entitled

AN INVESTIGATION OF THE FACTORS GOVERNING THE DISTRIBUTION OF SAVANNA PLANT COMMUNITIES IN NORTHERN AUSTRALIA WITH PARTICULAR REFERENCE TO GEOLOGY AND BEDROCK MINERALISATION.

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VOLUME CONTAINS CLEAR OVERLAYS

OVERLAYS HAVE BEEN SCANNED SEPERATELY AND THEN AGAIN OVER THE RELEVANT PAGE

FRONTISPIECE

Eriachne mucronata on the Dugald River Lode

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ABSTRACT

An investigation was made into the factors governing plant distribution in two areas containing lead-zinc and in one case, copper, mineralisation in Northern Australia.

The distribution of the major units within the savanna vegetation of the study-areas appears to be largely controlled by edaphic and drainage factors.

Distinct plant assemblages are developed over the ore-deposits. Although the assemblages are restricted to these environments, the individual species also occur in regions apparently devoid of mineralisation. In the area containing both lead-zinc and copper deposits, the same assemblage occurs on both types of mineralisation. The assemblage species are apparently better adapted to withstand higher concentrations of ore-metal in the substrate, and to absorb greater quantities of these metals, than the more widespread plants.

Zinc, copper and lead occur in decreasing order of abundance in plants from un-mineralised localities. Plants growing over the ore-deposits can absorb large quantities of all three metals, but the distribution of metal within the aerial parts varies. In some species, an increased rate of absorption of lead and copper occurs when the plants are growing on soils rich in these metals compared with their rate of absorption elsewhere. This may be related to intra-specific variations within the plants.

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P L A T E S

INTRODUCTION

Although the relationship between plant distribution and mineralisation has been the subject of a considerable number of investigations in Europe, Russia and the United States, no systematic work appears to have carried out in Australia. Moreover, the influence of the ore-metal content in the soil on the vegetation has been largely neglected in previous studies. This thesis presents the findings of an investigation into the factors governing plant distribution at two base-metal deposits in northern Australia.

The major part of the field work was carried out at the Dugald River lead-zinc Prospect, (Lat. 20°15' south, Long. 140°10' east), lying some 36 miles north-west of Cloncurry, Queensland, (Fig. I). In addition to the lead-zinc deposit, numerous small copper showings also provided suitable sites for the study of plant distribution in the vicinity of mineralisation. The geology of the area was well known from work undertaken by the supporting Company, and likewise the major vegetation units from a previous survey made by M.M. Cole.

In this area the present work was made in conjunction with a study of the geochemical dispersion of copper, lead and zinc from the ore-deposits by

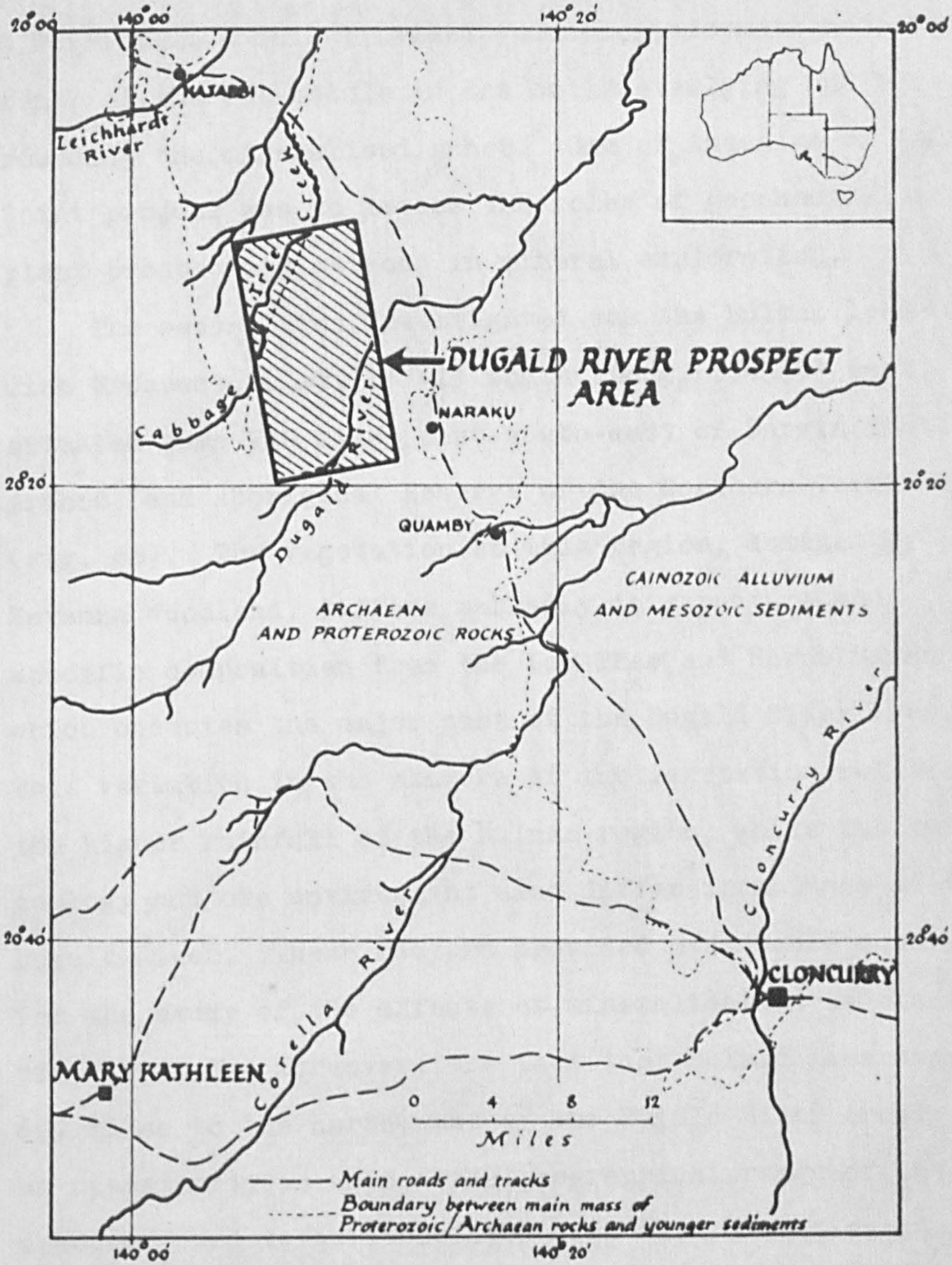

Fig. I. Location of Dugald River Area.

O.W. Nicolls. This provided valuable information on the tenor of the ore-metals in the soils overlying and surrounding the mineralised zones. One of the aims of this joint project was to assess the roles of geochemical and plant prospecting methods in mineral exploration.

The second area investigated was the Bulman lead-zinc Prospect, (Lat. 13°41' south, Long. 134°16' east), situated some 240 miles east-south-east of Darwin in the Arnhem Land Aboriginal Reserve of the Northern Territory, (Fig. 40). The vegetation of this region, dominantly Savanna Woodland, differs markedly in structure and specific composition from the Low Tree and Shrub Savanna which occupies the major part of the Dugald River Area. This variation in the stature of the vegetation reflects the higher rainfall of the Bulman region, while the soils, geology and ore environment also differ from those at the Dugald River. These factors provided a suitable contrast for the study of the effects of mineralisation on plant distribution. Moreover, the fact that Bulman lies some 600 miles to the north-west of the Dugald River Area gave an opportunity to assess the geographical range of the species found to be associated with mineralisation in the latter region.

The field work embodied in this report was carried out during the period April to November, 1962. Of this period, six months were spent at the Dugald River Area and the remainder at Bulman.

Previous work

While the land surveys undertaken by the C.S.I.R.O. have given a valuable insight into the geomorphology, soils and vegetation of parts of northern Australia, none of the published work covers the field areas described in this report. Moreover, the regions studied have been mapped on the basis of Land Systems, i.e. areas of similar topography, soils and vegetation, and not on the vegetation as such.

The mapping of the Barkly Tableland by Christian et al, (1954), terminates west of the Dugald River Area. Likewise, the Katherine-Darwin region, described by Christian and Stewart, (1953), lies west of Bulman. Although some of the associations and species mentioned in these reports have been found in the present studies, therefore, considerable variations in the vegetation are apparent.

Several other investigations have been made into the distribution of the major vegetation units in northern Australia but, like the C.S.I.R.O. surveys, the scale of the accompanying maps have been too small to be of much assistance in the present study. Blake, (1937), has described the vegetation occuring over a large sector of western Queensland. On his map, the vegetation of the

Dugald River region is indicated as a Eucalyptus brevifolia (ex pallidifolia)- E. leucophylla - Triodia community. However, E. leucophylla was not collected in the present study, while a considerable part of the vegetation of the region is dominated by species of Eucalyptus other than E. brevifolia.

The vegetation of the Arnhem Land Aboriginal Reserve has been studied by Specht and Mountford, (1958). These authors class the vegetation of the Bulman region as Tall Open Forest. In the same report, Bateman and Specht give a short account, with a species list, of the Bulman vegetation. However, most attention was apparently given to the area lying to the east of the Wilton River, (Fig. 41). Relatively few of the species listed were collected in the study area, while there is an overall dissimilarity in the major vegetation units.

It is extremely likely that the old prospectors used variations in the plant cover as a guide to ore in Australia. In 1897 Skertchley described the species Polycarpaea spirostylis F. Muell. in a report on the mines of the Watsonville district of eastern Queensland. This author first noted the plant in 1895 and, "subsequently found the plant in plenty over all the copper regions described in this Report". The species not only grew directly on the ore outcrops, but was also noted along watercourses draining the mineralised zones. Skertchley remarks that, in his experience, the plant could be detected more readily than the copper-bearing outcrops, and hence, "could be of real value in prospecting for this metal".

In a paper entitled, "Some Indicators of Ore Bodies", Lidgey, (1897), remarks ......

> "In the Bendigo district for many years and to a limited extent at present, it was considered that the Victorian Ironbark, (Eucalyptus leucoxylon) was a distinct indicator that the country on which it grew was auriferous, and that only thereon would payable reefs be found. There is a good deal of truth in the statement; yet it cannot be considered as invariably true, as payable reefs have been found where the Ironbark never grew".

While more recent investigations into the plant prospecting method are fairly common for regions with temperate climates, reference in the literature to their use in tropical regions are comparatively rare. In Rhodesia a study of the plants growing in the "copper clearings", sparsely-vegetated zones over near-surface copper mineralisation, was begun in 1949 and led to the discovery of the indicator plant, Becium (ex Ocimum) homblei (de Wild) Duvign. (Woodward, 1959). This species has been found at 28 out of 30 copper occurences from near Lusaka to the Belgian Congo: in the case of the two exceptions, the soils over the mineralised formations were deeply leached and were low in copper. The flower follows faithfully the line of the deposits investigated, its mapped distribution being almost identical in outline with the underlying ore-body. Occasionally, small clumps of the plant have been discovered some distance from mineralised zones. These occurrences, however, were almost invariably along "dambos" draining from known ore-bodies.

In neighbouring Katanga, Duvigneaud, (1958), and Duvigneaud and Denaeyer-de-Smet, (1963), have made wide-spread studies of the flora of the numerous mineral deposits which occur in this region. Separate florae characteristic of copper-cobalt-nickel, lead-zinc and manganese deposits have been described, and the species associated with mineralised occurrences classified according to their distribution within these areas.

In spite of the fact that the level of copper in the soils overlying the ore-deposits may reach very high concentrations, symptoms of metal toxicity in the plants are very rare unless the equilibrium has been recently disturbed, e.g. by recent mining. This contrasts with the situation in the Rhodesian copper clearings, where Duvigneaud and Denaeyer-de-Smet, (ibid), report that chlorosis and necrosis are very common. The authors therefore conclude that the flora of the Katanga deposits is in equilibrium with the environment. On the other hand, the absence of a well-adapted copper flora in Rhodesia is considered to be due to the lower tenor of copper in the soil overlying the ore-deposits, and to the fact that the mineralised zones are more widely separated.

Few studies have been made of the plant analysis, or biogeochemical, method of prospecting in tropical terrain, though again investigations in temperate regions have been more numerous, (see Section D). The concentration of lead, zinc and silver in the leaves and twigs of several species of savanna trees from the vicinity of lead-zinc mineralisation in Nigeria was studied by Webb and Millman, (1951). Lead was found to give biogeochemical anomalies many times wider than the lead-zinc lodes. The distribution of silver was erratic, but it was suggested that the element may have limited value as a path-finder, i.e. an element which can be used as a guide in searching for buried ore-deposits when the principal ore-metal cannot be easily traced, (Warren and Delavault, 1956). The status of zinc as an index mineral was lowered by the relatively poor sensitivity of this metal with the spectrographic method used for the analysis. Several lead-zinc anomalies were detected over virgin mineralisation, however, and the authors concluded that the tree sampling method might prove a useful prospecting technique.

The possibility of using plant prospecting methods in the search for uranium in Australia was investigated by Debnam, (1955). A simple uranium indicator was not discovered, though the tree <u>Xanthostemon paradoxus</u> was found to accumulate larger amounts of uranium than other tree species from the same locality.

Acknowledgements

The field work described in this thesis formed part of a joint study undertaken by the writer's supervisor, Professor M.M. Cole of the Geography Department, Bedford College, London, and Professor J.S. Webb of the Geochemical Prospecting Research Centre, Royal School of Mines, London, on behalf of Messrs. Con Zinc- Rio Tinto Pty. Ltd. of Australia.

Following discussions with Professor Cole and Professor Webb, and the former's preliminary investigations in Australia, the Company provided funds for two studentships, one in geochemistry and the second in biogeography-geobotany. The former was awarded to Dr. O.W. Nicolls and the latter to the present writer. The Company also provided generous field and travelling expenses, and made available the results of their extensive drilling and mapping operations.

Grateful acknowledgement is made to Professor Cole for her invaluable advice and assistance throughout the course of the project. The writer is particularly indebted to her for arranging facilities for the analysis of the soil and plant samples, for identifying many of the plants collected in the study, and for her helpful criticism and suggestions on the preparation of this thesis.

Much help and co-operation was also forthcoming from Professor Webb, who made available the analytical facilities at the Geochemical Prospecting Research Centre, and gave permission to the writer to attend a course in analytical methods there. Thanks are also due to many members of the staff of the Centre, particularly Mr. R.L. Stanton, for advice on the analysis of the plant samples.

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PART 1: GENERAL ENVIRONMENTAL FEATURES OF NORTHERN AUSTRALIA

For the purposes of this description, northern Australia is taken to be that part of the continent lying north of the Tropic of Capricorn. Particular attention is focussed on the central part of this region, in which both the Dugald River and Bulman Areas are situated, and on the interrelationships between the factors of climate, geology, geomorphology and soil on the distribution of the major vegetation units.

(1). Climate

The climate ranges from tropical, moderate to high-rainfall in the coastal regions to tropical, semi-arid to arid in the interior. The average annual rainfall in the eastern coastal districts commonly exceeds 60 ins., particularly heavy falls occurring where the south-east trade winds strike mountainous regions. In parts of the Northern Territory, the north-west summer monsoon produces annual rainfall figures in excess of 40 ins.

Proceeding inland, the rainfall and humidity show a marked decrease until, near the centre of the continent, desert conditions persist. The Bulman and Dugald River Areas lie in the semi-humid to semi-arid zone, with average annual rainfall figures of about 35 and 17 ins. respectively. Nearly all the rainfall received occurs between the months of November and April, though, particularly at

Bulman, light showers are not infrequent during the winter. The wet season is characterised by high temperatures, commonly in excess of 100°F., humid conditions and predominantly north-west winds. During the dry season the wind direction is reversed, the temperature and humidity falls and the diurnal variation increases.

The rainfall is sufficient to support tall Evergreen Rainforest in parts of the eastern coastal districts, while, for a similar reason, parts of the Northern Territory are occupied by dense Monsoon Forest. Inland, the long dry season has a marked effect on the vegetation. The overall height of the dominant stratum diminishes as the rainfall decreases. Many of the tree and shrub species are sclerophyllous and, particularly in the north, dry-season deciduous species are also common. The annual grasses and herbs survive the dry season as seeds, which germinate when the first rains of the following wet season are received. The perennials die back during the winter months, growth being resumed from vegetative buds at the onset of the rains.

The climate has had a marked effect, not only on the physiognomy of the vegetation types occurring within this region, but also on their distribution. This, however, will be discussed later in this section.

(2). Geology and physiography

On a geological and physiographic basis, the northern half of the Australian continent can be subdivided into three main units, namely: - the Eastern Highlands, the Great Australian Plateau, and the Artesian Basin.

The Eastern Highlands form the "backbone" of the continent, separating the narrow coastal strip with seaward drainage from the vast interior, where drainage is either north and west, to the Gulf of Carpentaria, or south-eastwards towards the Lake Eyre system. A wide range of rock types outcrop in the Highlands, the older formations now being strongly folded and in places intruded by igneous rocks.

The Great Australian Plateau occupies the major parts of the States of Western Australia and the Northern Territory, averaging between 1000 and 2000 ft. in elevation. In places smaller plateaux and ranges rise above the general level, such as the Macdonnell Ranges in the southern part of the Northern Territory, the Hammersley Ranges in the far west of Western Australia and the Isa Highlands in Queensland. The Plateau is underlain for the most part by Pre-Cambrian rocks, sometimes, as exemplified by the flat-lying Cambrian limestones of the Barkly Tableland, with a thin cover of younger sediments. Over the greater part of the region desert conditions prevail, and drainage is intermittent.

Separating the above two regions of upland relief, and covering the greater part of the State of Queensland, is a wide structural basin containing flat-lying sediments of Palaezoic, Mesozoic and Tertiary ages. North of the latitude of Cloncurry, (Fig. 1), the Great Artesian Basin is sub-divided into two smaller sub-basins by the Euroka Ridge : in the Carpentaria division to the north, drainage is towards the Gulf of Carpentaria, while in the southern,Eromanga basin, inland drainage persists.

The Dugald River Area lies near the border between the Isa Highlands, which form a narrow upland range of Pre-Cambrian rocks protruding in a north-north-west direction from the Great Australian Plateau, and the wide plains of the Carpentaria sub-basin. The Bulman Area occupies a similar position with respect to the Australian Plateau, occurring near the boundary between this unit and the lower Arnhem Land Plateau in the far north of the continent.

The wide plains and steep-sided residuals of the central part of the continent leaves little doubt that processes of pediplanation, by scarp retreat and the formation of pediments, have played a major part in fashioning the present-day land surface. In the Eastern Highlands the relief has been influenced by the large-scale folding and faulting which affected the region in

Mesozoic and Cainozoic times, but even here remnants of former Cretaceous and Tertiary pediplains stand out as plateau remnants.

There seems to be general agreement that at least three periods of subaerial erosion have occurred. The earliest predates the Mesozoic sedimentaries of the Artesian Basin, the Gondwana Surface of King, (1949), while the two later periods have been assigned an early- to mid-Tertiary and a late-Tertiary age by Twidale, (1956). This author has suggested that lateritisation may have accompanied the earliest cycle, but the main period seems to have occurred in late Tertiary times.

(3). Soils

With the exception of the lateritic soils, which show evidence of having been formed under more humid conditions than prevail in northern Australia at present, the majority of the soils occurring within the region are characterised by the lack of any well-defined textural differentiation.

Profile development has been arrested by a variety of factors, such as the lack of a dense vegetative cover, thereby leading to increased erosion, and the low rainfall. The seasonal distribution of the rains, and their short-lived, but sometimes intense, nature, provides conditions for the rapid removal of accumulated degradation products by sheet-wash erosion. Moreover, the fact that a large part of the region seems to have but recently emerged from below a cover of older soils, means that the processes of soil formation have only been able to act on the exposed rocks for a relatively short period of time. Hence, in most cases, the developing soils are at a relatively juvenile stage.

Large parts of the upland areas, such as the Isa Highlands, the Eastern Highlands and the Arnhem Land Plateau, are occupied by Skeletal Soils. These consist of shallow, gravelly soils with a large proportion of coarse-textured material derived from the underlying bedrock. Large sectors of both the Dugald River and Bulman Areas are occupied by this soil type. The soils are extremely variable, their characteristics being largely governed by the nature of the parent material.

As mentioned above, relicts of lateritic soils are widespread throughout northern Australia, and occur in the Dugald River and Bulman Areas, though particularly common in the latter. Residual Lateritic Podsols and Sandplains occupy a large part of Cape York Peninsula, smaller areas near the Gulf of Carpentaria and parts of the Eastern Highlands. They comprise deep, highly-leached profiles with abundant ironstone gravel and a layer of nodular, pisolitic or massive laterite. Beneath this horizon, zones of mottled and white kaolinitic clay are generally present : these are termed the Mottled and Pallid Zones respectively. Within these horizons, an intermittent zone of siliceous material - Silcrete - is sometimes developed. The soils are deficient in trace elements and extremely low in phosphorus.

The lateritic soils occur on tableland relics and plateaux of supposed Pliocene age, (Stephens, 1962), when the land surface was apparently one of low relief and more humid conditions prevailed than those at the present day. The laterite and companion materials are considered to have been formed under the influence of a seasonally fluctuating water table, by deposition of the iron and aluminium oxides in the form of laterite, and removal of iron in solution from the kaolinitic horizons below.

At present, some small areas have the original soils, but over the greater part of the region the profile has been destroyed by subsequent weathering. In the Dugald River Area the laterite and pallid zones are still preserved on the summit of an isolated mesa of Mesozoic rocks, but elsewhere this soil type is represented only by scattered ironstone nodules and ferruginous stains. Remnants are more extensive in the Bulman Area, however, though here the original laterite horizon has been largely removed. Large parts of the region are underlain by a deep layer of fine-grained white chert - the silcrete horizon - covered by a veneer of laterite nodules in a fine-textured matrix.

The wide alluvial plains of the Barkly Tableland and the Great Artesian Basin are occupied by the Grey and Brown Soils of Heavy Texture. These consist of a uniform, grey or brown clay, several feet in thickness, with small amounts of lime and gypsum near the base. During periods of prolonged dry weather the whole profile may be traversed by a series of vertical or sub-vertical cracks, an inch or two in width, while during the rainy season the soils are generally flooded.

This soil type is represented on the flood plain of one of the major rivers which traverse the Dugald River Area, while a closely-allied soil gives rise to the low-lying Black Soil Plains in the Bulman region. Stephens, (ibid), considers these soils as weakly-hydromorphic soils which have developed on fine-textured alluvial material in areas subject to occasional flooding. The latter has been sufficient to produce the hydromorphic characteristics, without removal of the lime and gypsum present in the profile.

Though its small scale detracts from its value, (thus the lateritic soils in the Bulman region are not represented, even though they here occupy quite a wide area), the soil map of Australia prepared by Taylor, (1955), provides useful information on the factors controlling the distribution of the major soil types. The Skeletal Soils are largely restricted to the upland regions, where present-day erosion suffices to remove the bulk of the finer-textured material as it is formed. From the distribution of the Residual Lateritic Podsols and Sandplains, it is probable that these once covered large areas now occupied by the Skeletal Soils. This, too, has had an important influence on the extent of these essentially nascent soils.

Conversely, the lateritic soils are restricted to those areas where the former land surfaces on which they were developed have been little affected by subsequent dissection. In regions of low elevation, such as those to the south of the Gulf of Carpentaria, the lateritic relics have been preserved by virtue of the low erosional powers of the rivers which traverse these plains. When occurring in upland areas, however, their preservation is related to the fact that these regions are largely sheltered from the effects of present-day fluviatile erosion. Examples of this type of occurrence are to be found on parts of the Barkly Tableland and on the Eastern Highlands.

The former geomorphological history also has a close bearing on the present-day distribution of the Grey and Brown Soils of Heavy Texture. It will be recalled that these soils occur on low-lying areas of fine-textured material. This may be of fluviatile origin, as on the flood plains of the former or existing river systems which traverse the Artesian Basin, or of lacustrine or swamp origin as on the Barkly Tableland in the Northern Territory, (Christian et al, 1954).

Although the climate has a marked influence on the character of the soils now occurring within the region, serving to keep them at a comparatively juvenile stage of development, it appears to be a relatively unimportant factor amongst those governing their distributions. This is related to the lack of any major relief features, and consequently the absence of any abrupt climatic changes, throughout the central and northern parts of the continent. Prior climatic regimes of more pluvial conditions have had an important bearing on the characteristics of the lateritic soils, however. Likewise, past geomorphological history has been a major influence on the distribution, not only on these soils, but on that of the other major soil types.

(4). Vegetation

The classification used in the vegetation map of Australia by Williams, (1955), is based primarily on the structure and life form of the vegetation units and largely ignores floristic composition. The vegetation has been subdivided into five "forms", i.e. Forest, Woodland, Shrub Communities, Savannah and Grassland. Within these divisions "sub-forms" have been recognised using the criteria of leaf texture of the dominants, whether the dominants are single- or multi-stemmed, and whether uni- or multi-storeyed.

The following description of the vegetation units occurring in the central and northern parts of the continent is based on the sub-forms. It should be added, however, that these are made up of numerous vegetation "associations" and "communities", which, in contrast to the larger units, are classified on the basis of their floristic composition. These subdivisions have been used for the classification of the vegetation of the Dugald River and Bulman Areas. Finally, within the associations and communities, plant "assemblages" may be recognised, composed of a small number of individual species whose distribution is restricted to relatively small areas and, generally speaking, to a narrow range of habitats. Examples of such assemblages are those occurring over the ore-deposits within the study-areas.

Forests are restricted to the high-rainfall districts of northern Australia, as on the coastal strip of eastern Queensland and in the north-west coastal districts of the Northern Territory. Inland, these give way to a variety of sub-forms, of which the Tropical Woodland is the most abundant. This is an artificial group brought together for mapping purposes, and including Tropical Savannah Woodland, Tropical Deciduous Woodland and Tropical

Layered Woodland. These occupy a wide belt of country with moderate to high rainfall in the northern parts of Western Australia and the Northern Territory, and on the Eastern Highlands in Queensland. The climate of these regions is characterised by a pronounced dry season of between three and nine months. The vegetation is therefore adapted to long periods without significant rainfall. Many of the tree and shrub species have sclerophyllous leaves, while in the Deciduous Woodlands the dominants are deciduous or part-deciduous.

The dominant stratum forms an open canopy, sometimes, as in the Layered Woodlands, with a subordinate layer of smaller trees, 7 to 10 m. in height. A sparse shrub stratum is generally present, while the ground storey is dominated by a fairly dense growth of annual and perennial grasses. In higher-rainfall areas, as in the northern parts of the Northern Territory, these may reach a considerable height.

The Tropical Woodland sub-forms occupy a wide variety of soils, ranging from Skeletal Soils to Residual Lateritic Podsols and Sandplains, and occur in regions differing markedly in relief and elevation. It would seem, therefore, that their distribution is largely governed by climatic factors, of which the most important is probably the seasonal nature of the rainfall.

The vegetation of the Bulman region is dominated by

Tropical Savannah Woodland, but as the climate becomes drier towards the interior of the continent, this, and the allied sub-forms, are replaced by a complex of Low Arid Woodland, Sclerophyll Low Tree and Sclerophyll Shrub Savannah. These occupy a wide belt, which includes the Dugald River Area, south of the northern development of the Tropical Woodland. Eastwards, they give way to Semi-arid Tussock Grassland and Semi-arid Shrub Savannah on the wide plains of the Artesian Basin.

The Low Arid Woodland is the most widespread of these sub-forms. The dominant trees, often Eucalyptus spp., are generally of a lower stature than those of the Tropical Woodlands. Generally they do not exceed 10 m. in height, with an open to almost continuous canopy. Subordinate strata of shrubs or sub-shrubs are sometimes present, while the ground layer, generally discontinuous, consists of a high proportion of short-lived annual species. In some regions, however, the perennial grass, Triodia spp., forms the dominant of the herbaceous layer.

With an increase in the spacing of the dominant stratum, this sub-form grades into those of the Scleropyll Low Tree or Schlerophyll Shrub Savannahs. In these the tree or shrub layer is generally composed of species of Eucalyptus, Grevillea, Hakea or Acacia. The herbaceous layer is dominated by sclerophyllous hummock-forming grasses, such as Triodia spp. Much bare ground is present between the hummocks, though after rains the intervening areas may be occupied by numerous ephemeral herbs and grasses.

Although largely restricted to regions occupied by Skeletal Soils, the Low Arid Woodland and associated sub-forms are also developed in areas of deeper soil, such as the Lateritic Sandplains. The Woodland sub-form is found throughout the region between the 30 and 10 in. isohyet : towards the latter it occurs on light ridge soils, on alluvial soils near watercourses, or at the base of rocky outcrops, where run-off water is available, (Williams, 1955). It would appear that the distribution of these various sub-forms is largely governed by those edaphic factors which affect water supply. The lower stature of the dominant species within each stratum, compared with those of the Tropical Woodlands, is related to the more rigorous climatic conditions under which these sub-forms exist.

To the south of the main development of the Low Arid Woodlands, the wide tracts of Grey and Brown Soil of Heavy Texture in Western Queensland and the Barkly Tableland are occupied by the Semi-arid Tussock Grasslands. These are dominated by coarse xeromorphic tussock grasses, chiefly <u>Astrebla</u> spp. and <u>Iseilema</u> spp. Williams, (ibid), considers that, "the grassland is the natural climax vegetation, limited within the 10 to 18 in. rainfall zone by heavy soils with a relatively high nutrient status and moderate to poor drainage". As previously mentioned, these soils occur to a limited extent in the Dugald River Area, and here carry the characteristic vegetation described above.

Minor areas of light-textured soils within the Grassland zone are occupied by Semi-arid Low Tree and Semi-arid Shrub Savannah. These comprise a low tree or shrub layer, 5 to 8 m. in height, with a discontinuous ground storey largely composed of annual grasses.

Whereas the climate is apparently the dominant factor governing vegetation distribution in the higher-rainfall districts of nothern Australia, other factors assume a greater importance as the climate, particularly the rainfall, becomes more limiting. Thus the Forest and Tropical Woodland sub-forms, while restricted to a relatively narrow range of climatic conditions, occur in regions markedly different in soil type and elevation. Inland, it appears that those factors, chiefly relief and soil depth and texture, which control the supply of water to the plant roots have the greatest influence. Thus low-lying areas subject to occasional flooding support Semi-Arid Tussock Grassland. The absence of trees from this environment is presumably related to the water-logged condition of the soil during the wet season. On the other hand, the better-drained Skeletal Soils and Lateritic

Sandplains, which normally occur on higher ground, carry a woodland or savanna vegetation.

The marked effect which the soil-moisture status has on the distribution of the major vegetation units has been borne out by the studies in the Dugald River and Bulman Areas.

PART II: FIELD TECHNIQUES

(1). Vegetation studies

(a). Transects

Transects were directed towards gaining a quantitative estimation of the variations in the herbaceous, shrub and tree strata within areas of interest. After initial reconnaissance, suitable traverse lines were laid out, generally at right angles to the direction of the boundaries between the vegetation units.

A quadrat, consisting of a wire square measuring 3 by 3 ft., was used to record the changes in the ground vegetation. Where this showed much variation the transect was generally made continuous, but where little diversity was apparent the quadrat interval was increased appropriately. Four quadrats were taken at each sampling point, giving a final quadrat size of 6 by 6 ft. Within this area, the percentage of the ground covered by each plant species was recorded, while notes were also taken on the slope, geology, height, cover by trees and shrubs, etc. A count was made of the number of tree and shrub species at intervals along the transect, using a quadrat size of 100 by 100 ft.

Variations in the soil along the transect line were recorded from profile pits and by augering. Height measurements, using an Abney Level and Aneroid Barometer, (see below), were then taken, and soil samples collected from each soil type represented within the transect. Samples were stored in numbered Kraft paper bags.

(b). Mapping

Small-scale maps of the vegetation of the Dugald River and Bulman Areas were prepared by plotting the dominant species of each stratum directly on to aerial photograph enlargements. In the former area, ground control was established from an accurately surveyed base line. The vegetation of this area was also surveyed and photographed from a small aircraft, giving valuable information on the distribution of the major vegetation units and providing a check on the ground work.

Selected areas were mapped on a larger scale. A grid was laid out in the field, and variation in the vegetation plotted on squared paper at a suitable scale, normally 1 in. to 100 ft.

(2). Soils

In addition to the soil studies made along the transect lines, further profile pits were sunk in areas illustrative of the major soil types occurring within the regions. The profile exposed in the pit was described and photographed. The texture of the various horizons was recorded using the method described in the, "Field Handbook", of the Soil Survey of Great Britain. Colour measurements were made on the Munsell Scale, and an estimation of the amount of lime present obtained with dilute hydrochloric acid. Supplementary information on the slope, rock type, surface features and vegetation were recorded at each profile pit. Soil samples for geochemical and major/trace element analysis were collected from each soil horizon.

(3). Geochemical sampling

As mentioned previously, the Dugald River work was made in conjunction with an investigation of the geochemical dispersion of copper, lead and zinc in the rocks, soils and stream sediments of the area, undertaken by Nicolls, (1964). Since extensive use has been made of Nicolls' results for the soils in the discussions of plant distribution in mineralised areas, and since the technique was used by the present author in the Bulman Area, a short account of the methods used is given here. For a fuller description, reference should be made to his thesis.

Soil samples were normally collected from a depth of 4 to 6 ins., though in areas of transported overburden deeper sampling was required. After a series of analyses on the different size fractions in a number of soils, it was decided to use the minus 80 mesh material for routine sampling. It appeared that the contrast between the samples was best in the coarser material, but the representativity of such a sample would be poor at the 0.I or 0.2 gm. sample weights required by the analytical procedure. The analysis for "Total" metal content was carried out using a potassium bisulphate fusion followed by a hydrochloric acid leach. The colorimetric procedures used for the determination of copper, lead and zinc in the soils formed the basis of the methods used for the analysis of plant ash by the present writer, and are listed in Appendix B.

The samples were normally collected along a series of traverses laid out at right angles to the strike of the country rock. The sampling interval was generally 100 ft., decreasing to 25 ft. or less in areas of interest. Over the Dugald River Lode Area, a traverse interval of 500 ft., proved satisfactory, though in areas of less extensive mineralisation a closer interval was used.

The results of the analyses of the samples along the traverses were either graphed, as indicated in the diagrams showing the results of the botanical transects, or plotted on a base map and contoured as in Fig. 5. The results so depicted allowed the definition of "Geochemical Anomalies", or areas where the soils contained abnormal quantities of the ore-metals.

Stream sediment samples were collected from the surface, (0 to 2 in.), layer. For all routine work the fine sand, where available, was selected for sampling. A sampling interval of 1500 to 2000 ft. was found suitable for detecting copper, lead and zinc dispersion trains of economic significance.

(4). Physiography

No contour maps were available for the areas studied and aerial photographs were therefore used. These are extremely valuable in location, and for plotting the changes in the vegetation or soil, physical features, etc., but they have the disadvantage that the scale alters away from the central point of each photograph.

Height measurements were made by means of an Aneroid Barometer and Barograph. The latter was set up at the camp site in each area and the Aneroid adjusted so that each instrument was reading the same pressure. The barometric pressure was read on the Aneroid at suitable points in the field and the time noted. The difference in pressure between the reading at this locality and at the camp site was obtained from the Barograph Trace and converted into feet, (one inch of pressure being approximately 92 ft. of height). This information was plotted on a base map and, with the aid of the aerial photographs, rough form line maps could be obtained, (Fig. 4A).

The height of the Dugald River camp site was estimated by taking simultaneous Aneroid readings at this locality and at the nearest surveyed height, (Quamby

Station, see Fig. 1). The lack of suitable surveyed points in the Northern Territory precluded a similar estimation of the height of the Bulman camp site.

PART III: THE DUGALD RIVER AREA

Introduction

The reasons governing the choice of this area as a suitable site for the field work have been referred to in the Introduction to this thesis. The area takes its name from the Dugald River, which flows north and east to the Gulf of Carpentaria and forms the south-east margin to the study-area. This lies some 36 miles north of Cloncurry, and contains a low-grade lead-zinc ore body, the Dugald River Lode. Numerous small copper showings also occur in the calc-silicate rocks which underlie a large part of the region, and these also afforded the opportunity for the study of plant distribution in the vicinity of mineralisation.

The initial survey indicated that both the lead-zinc and copper deposits were generally occupied by plant assemblages differing markedly in appearance and floristics from the neighbouring vegetation on unmineralised rocks. The status of these assemblages within the vegetation hierarchy of the region, however, was dependent on the recognition of the major vegetation units. These were therefore mapped over a wide area, and the influence of geology, geomorphology, relief and soils on their distribution investigated. One area remote from known mineralisation, named the "Area north-east of the

Quartzite Range", was selected for study in greater detail. Several of the species occurring in the vicinity of the ore-deposits were noted here. Moreover, the variations in the vegetative cover within the area well illustrated the effect of edaphic factors on plant distribution. Large-scale maps of this area were prepared, showing both variations in the tree and shrub cover and in the herbaceous stratum.

Similar maps were made of the major vegetation units in the region surrounding the lead-zinc deposit. The distribution of the assemblages developed over the ore-body was mapped and a series of belt transects made across the mineralised zone. These sought to gain a quantitative estimation of the variations in the vegetative cover within the area. The transects were laid out at right angles to the strike of the ore-deposit and sited to traverse areas where different plants dominated the assemblages, and to cut across regions differing in relief, drainage and ore content. Variations in the soils occurring along the transects were recorded from pits, and soil samples collected for major element, spectrographic, and geochemical analysis. A full description of the techniques used is given in the preceding section.

The marked correlation between certain plants and the ore-deposits in the Lode Area led to reconnaisance over a wider area and the discovery of an extensive zone of the assemblage species on copper-stained shales in an area about six miles north-east of the lead-zinc body. This locality was termed the Turkey Creek Area. The investigations into the factors controlling plant distribution in this region followed identical lines to those in the Lode Area.

It was felt that a comparison of metal uptake between the species comprising the assemblages and the more widespread plants might yield information on the factors governing their respective distributions in the vicinity of the ore deposits. Samples of the assemblage species and the abundant grass, Triodia pungens R.Br., were therefore analysed for copper, lead and zinc. A series of plant samples from the vicinity of the Lode was analysed spectrographically to indicate whether variations occurred in the distribution of other elements besides the ore-metals.

Samples of the assemblage species were also analysed from occurrences remote from known mineralisation. These were collected to determine whether the plants, or the underlying soil, at these localities contained anomalous quantities of ore-metal. Any enrichment might, in this case, indicate that the occurrence of the plants was related to the presence of unsuspected mineralisation at depth.

SECTION A: THE CLIMATE, GEOLOGY, PHYSIOGRAPHY AND SOILS

(I). Climate

The climate is tropical monsoonal with well-defined wet and dry seasons, nearly all the rain being received between November and April. Day temperatures are high throughout the year, but particularly during the months of October, November and December prior to the onset of the rains.

The rains fall principally as summer storms which sweep across belts of country a few or tens of miles wide : a typical storm may yield one to three inches of rain. For this reason, the distribution of rain within any one year is generally patchy. Some general monsoonal rains, however, drench the whole countryside.

During the winter the dominant wind direction is from the south-east. These cool, dry winds produce a sharp fall in temperature and humidity. In the summer, winds are generally moisture-laden monsoonal winds from the north-west.

Rainfall and other statistics for Cloncurry are shown in Table 1. The average annual maximum temperature is about 90° F and average annual rainfall around 17 ins. The rainfall figures for Carsland Homestead, approximately half-way between Cloncurry and the Dugald River Prospect, are also indicated for the years 1960-62. These are

Table 1 : Climatic Statistics for Cloncurry.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Average rainfall, inches,	4.73	3.96	1.86	0.62	0.48	0.80	0.23	0.12	0.16	0.44	1.59	1.90	16.89
No. of wet days	7	7	4	2	1	2	1	0	1	2	3	5	35
Max. temp., ^{o}F	98.8	96.8	94.6	90.3	83.1	77.4	76.7	81.7	88.3	95.1	98.3	99.7	90.1
Min. temp., ^{o}F	73.3	75.4	72.8	67.0	59.7	54.1	51.5	54.8	61.2	68.6	73.4	75.9	65.9
9am. Rel. humidity %	44	48	47	37	39	44	41	32	30	29	34	39	39
3pm. Rel. humidity %	29	32	32	26	27	30	27	20	19	20	24	26	26

Rainfall Figures for Carsland Homestead (Approximately 20 miles NW Cloncurry).

Year.													
1960	2.41	1.33	0.40	2.33	0.75	-	-	-	-	-	2.00	2.74	11.96
1961	1.04	3.51	-	0.43	-	-	-	-	-	-	0.83	1.30	7.11
1962	2.33	2.29	3.04	0.31	0.26	-	-	-	-	-	0.20	0.97	9.40

Sources:- Cloncurry; R.O. Slatyer, "Climate of the Leichardt-Gilbert Area", in General Report of the Leichardt-Gilbert Area, Queensland, C.S.I.R.O. Land Res. Series, (in preparation).

Carsland; C. McMillan, Esq.

probably not very reliable, but they indicate the marked paucity of rainfall during the years prior to the present study. This has apparently had a marked effect on the growth of the most widespread shrub species, *Acacia chisholmi* F.M. Bailley, which in places is represented only by dead stalks and branches.

Features of the climate of importance to the vegetation are the long dry season and the coincidence of the period of maximum rainfall with that of high temperatures. The vegetation is therefore seasonal in aspect, maximum growth occurring during the summer and dying back in the dry winter. Many of the grass and forb species are annual, while in several of the perennial grasses the aerial parts die off during the dry season, and growth is resumed from vegetative buds at the onset of the rains.

(2). General geology

The Dugald River Area lies near the north-eastern margin of the Mt. Isa-Cloncurry mineral field of western Queensland. The ore-deposits occur in Precambrian rocks, which give rise to a rugged range of upland country projecting northwards as a spur from the main development of the Australian Shield. Eastwards the older rocks disappear below a cover of flat-lying Mesozoic sandstones and siltstones which underlie a large part of the Artesian Basin.

The Precambrian rocks have been the subject of numerous geological investigations, recently summarised by Carter et al, (1961), by virtue of the wide variety of economic minerals which they contain. The main metals which have been produced are copper and gold, though uranium, zinc, lead, silver, cobalt and tungsten have been mined in small quantities.

Carter et al, (ibid), have assigned a Lower Proterozoic age to the rocks occurring within the Precambrian belt. They are considered to have been deposited in a north-south trending basin whose sediments were derived from an Archaean foreland to the west. Subsequent uplift to the east of Mt. Isa caused the formation of two smaller basins. Within the eastern basin the sediments of the Corella Formation, which underlies the greater part of the Dugald River Area, were deposited. The area also contains a thick deposit of siliceous sandstones and conglomerates, the Knapdale Quartzite, but the relationship between this unit and the Corella Formation are obscure. As discussed below, they may belong to the same formation.

The Precambrian rocks have undergone considerable deformation. The sediments of the Corella Formation are now represented by a variety of metamorphosed and metasomatised rocks, including calc-silicates and calc-silicate breccias, granulites, quartzites, slates and mica-schists. Although not a common feature, lenses of graphitic shale are of considerable economic interest, since they form the host rocks for the lead-zinc mineralisation both in the Dugald River Area and at the larger Mt. Isa deposit.

In places the Corella Formation has been intruded by granites, the nearest occurrence being the Naraku Granite some eight miles to the south-east of the Dugald River Lode, (Fig. 1). Extensive faulting has also occurred. Within the study area the north-south Mt. Rosebee fault zone, which forms a series of prominent ridges near the eastern margin, is probably the largest, (Plate 1).

The regional strike of the rocks within the Dugald River Area is NNW to SSE, (Figs. 2 and 3A), with a general dip of between 60 to 70° to the west. It has been suggested, (Knight, 1948, 1953), that the rocks form a large overturned fold, with the Knapdale Quartzite as the core and the sequence of rocks exposed to the east of the Quartzite repeated on the west. Although the two successions bear certain similarities, the evidence from sedimentary structures, (ripple marks, current bedding), indicates that the entire sequence youngs westwards, (Thomas, 1961).

The relationship between the Quartzite and the Corella Formation, which surrounds the former unit, are obscured by faulting and poor exposure. Some of the contacts are clearly discordant, but faults have not

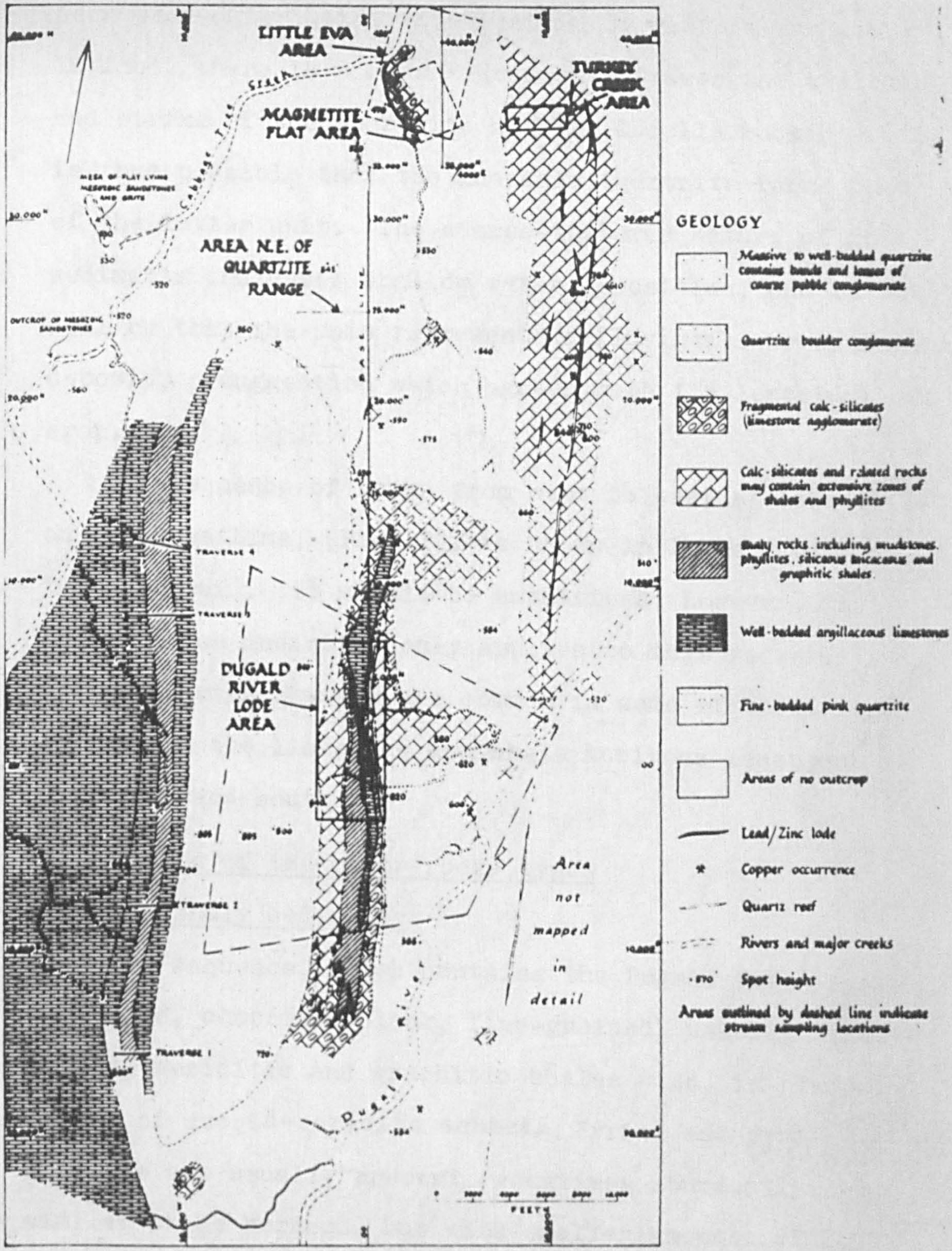

Fig. 2. Geological Map of Dugald River Area, showing Study-Areas.

been proved for either the eastern or western margins. In fact, there is a close agreement between the attitude and strike of the Quartzite and the Corella rocks, and it is thus possible that the Knapdale Quartzite forms part of the latter unit. The coarse-textured nature of the sediments indicates shallow water deposition, and it may well be that the unit represents a fluviatile or estuarine deposit, a suggestion which agrees with its lensoidal outcrop.

The sequence of rocks from west to east at Line 1200N on the Base Line, (Fig. 2), is shown in Table 2, (after Thomas, 1961). It should be emphasised, however, that the sequence indicated only applies to this sector. Lateral facies changes are common in some of the units, while both the limestone and shale horizons lense out to the north and south.

Description of the major rocks types

(i). The shaly sediments.

This sequence, which contains the Dugald River lead-zinc lode, comprises black, fine-grained, usually finely-bedded, sericitic and graphitic shales with, in places, lenses of quartz-sericite schists. Pyrite and pyromorphite are usually present, sometimes abundantly. A similar shale horizon, but with smaller amounts of lead and zinc, occurs to the west of the Knapdale Quartzite, (Fig. 2).

Table 2: The Sequence of Rocks from West to East on Line 1200N, Dugald River Area.

Description	Approximate Thickness (Ft.)
Dark argillaceous limestones	8000
Andalusitic graphitic shales and schists	800
Dark argillaceous limestones	800
Knapdale Quartzite	10000
Calc-silicates	1500
Fragmental calc-silicates	500
Interbedded shales and mica-schists	300
Graphitic shales with Western Lode	100
Siliceous shaly mudstones	100
Dark argillaceous limestones	60
Micaceous Hangingwall shales	60
Dugald River Lode	10
Micaceous Footwall shales	100
Dark argillaceous limestones	400
Fragmental calc-silicates	100
Fine-bedded quartzite	80
Calc-silicates	12000

The host rock of the lead-zinc mineralisation is a dense, often contorted, black, graphitic and occasionally chlorotitic shale. It is veined by fine-grained sulphides, predominantly sphalerite, pyrite and pyrrhotite. Chalcopyrite is sometimes present.

(ii). <u>The banded argillaceous limestone</u>

This rock is a distinctive black, very well-bedded, probably dolomitic limestone with an abundance of argillaceous material, now present as blebs of andalusite, biotite, sericite and graphite. Several horizons occur in the area, and some show a considerable variation along strike.

(iii). <u>The quartzite</u>

The main mass of quartzite, (the Knapdale Quartzite), is massive to well-bedded, with ripple marks, current bedding and other features indicative of shallow water deposition. The sequence contains thick bands and lenses of coarse pebble and boulder conglomerate. A thin band of fine-grained quartzite also occurs about 300 yards east of the Dugald River Lode.

(iv). <u>The fragmental calc-silicates (limestone agglomerate)</u>

The typical fragmental calc-silicates consist of poorly-bedded, coarse-grained reddish rocks with abundant fragments of quartzite, quartz and, more rarely, limestone and shale. In thin section the rock is seen to consist essentially of quartz, felspar, calcite, magnetite, haematite and biotite. Variations in the proportions of quartz and calcite give rise to siliceous and limy varieties respectively. The former outcrops as rocky ridges while the more calcareous types, being less resistant to erosion, form lower ground.

(v). The calc-silicates

This rock type is widespread in the region, particularly near the Mt. Rosebee Fault Zone where it gives rise to low, undulating country. From scattered exposures in creeks, however, it is probable that it underlies much of the covered ground east of the Lode Ridge. A limy and a micaceous variety may be recognised. The former is a reddish or greenish, medium to coarse-grained rock consisting essentially of calcite, quartz, plagioclase and haematite. The micaceous type is a reddish-brown, medium-grained rock, with a lower proportion of calcite and more mica than the limy variety.

(vi). The scapolite granulites

This rock type has been described by Edwards and Baker, (1953). The typical granulite is a banded, equigranular rock, consisting of scapolite, pyroxene and sphene. Bands of scapolite marble and scapolite biotite schist are associated with the granulites.

Mesozoic

Outcrops of this formation are confined to two localities in the north-west of the Dugald River Area, (Fig. 2). The largest exposure occurs on a mesa, which rises about 100 ft. above the surrounding plain. The sides are comprised of soft yellowish sandstones and grits containing rounded quartz pebbles, while the summit is formed of several feet of indurated laterite.

A second exposure, consisting of soft red and grey sandstones, was noted in the bank of Cabbage Tree Creek south of the above locality, (Plate 3).

No fossils were noted at either of these outcrops, but it is probable that the sediments occurring in the Dugald River Area are roughly equivalent to the Normanton Formation of Cretaceous age. The type locality is at Normanton, about 170 miles to the north, where the formation comprises grey, fine, lithic sandstones and dark grey siltstones and shales. It is of interest that at this locality the top of the formation is also lateritised.

(3). Mineralisation

(a). Lead-zinc

With the exception of a shale sequence lying west of the Knapdale Quartzite, which contains minor amounts of lead and zinc as indicated by geochemical sampling, (Nicolls, 1964), the only occurrence of these metals within the area is at the Dugald River Prospect.

The deposits here are masked in places by ferruginous gossans, with showings of red and yellow iron oxide, cerussite and yellow lead oxide, (massicot), and possibly the red lead oxide, (minium), (Carter et al 1961). The Lode* outcrop forms a ridge, more or less barren of trees and the more widespread shrubs, over a mile in length, (Frontispiece).

The main mineralised zone occurs in a north-trending shear in contorted graphitic shales. Mineralisation can be traced along the strike for more than a mile, but the main ore shoot is 700 ft. long and 40 ft. wide at the surface. In addition, a much smaller deposit, the Western Lode, outcrops about 300 ft. west of the main zone. The chief ore minerals are galena, pyrrhotite, pyrargite and arsenopyrite.

The shale sequence containing the Lode has a very restricted distribution, forming a narrow belt about four miles in length. To the north it lenses out between the limestone and fragmental calc-silicate horizons. Southwards, the shale sequence thickens considerably at first,

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* Throughout this work the major lead-zinc deposit of the Dugald River Area will be referred to as the Lode.

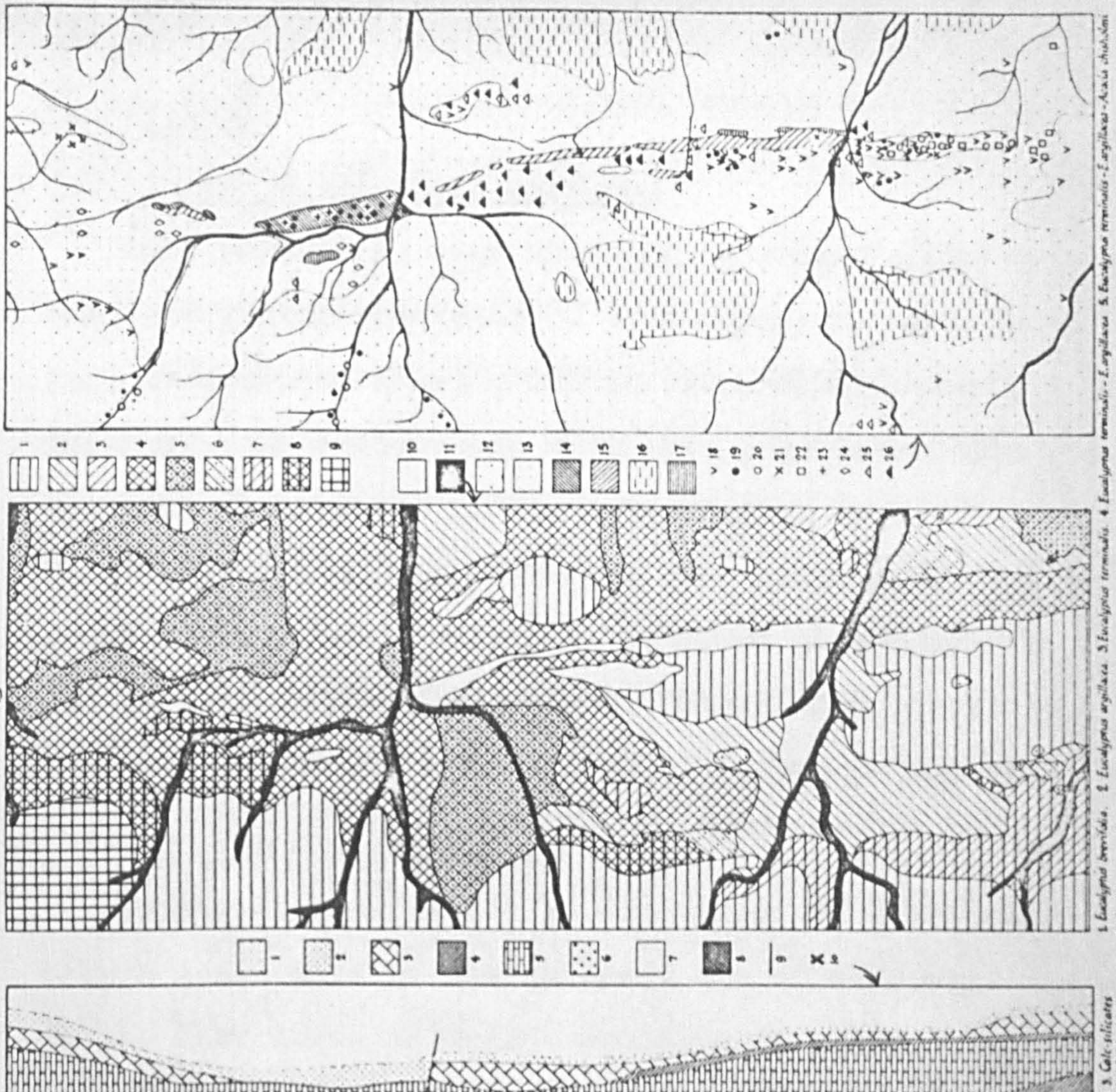


Fig. 3 A,B,C Maps of the Dugald River Lode Area, showing Geology, Distribution of the Dominant Trees and Shrubs, and the Ground Vegetation

then begins to lense out between bands of calc-silicates.

(b). Copper

(i). In the black shale sequense

Only relatively weak showings of copper occur in this unit. Drilling has revealed that copper is exceedingly rare in the Lode itself, but at the northern extremity malachite, in association with some quartz and ferruginous boxworks, is exposed in the Lode shales.

A second zone occurs in the Lode hangingwall near its southern end, where malachite is found in several places in bands of quartz mica schist. Other showings in this area are associated with lenses of gossanous material.

(ii). In the calc-silicates

Copper mineralisation is widespread in these rocks, though again most of the showings are of weak development. In the Lode Area, malachite staining is common along the shale-calc-silicate contact west of the Lode, (Fig. 3A), and numerous small workings have been exploited in the past. An abundance of malachite is evident in the material of the dumps, which largely consists of fragmental calc-silicates and calcite.

At the Little Eva Mine, (Fig. 2), a shaft has been sunk to a depth of about 60 ft. and both primary and secondary copper minerals worked. The immediate area south and west of the mine is dotted with numerous small pits and dumps. Malachite staining and occasional specks of chalcopyrite have been traced, though in a dispersed form, over an area measuring about 600 ft. in width and 800 ft. long.

(iii). Other occurrences

Near the western boundary of the Knapdale Quartzite, malachite and azurite has been found in fine-grained biotitic sandstones. This is the only occurrence known within the Quartzite Range.

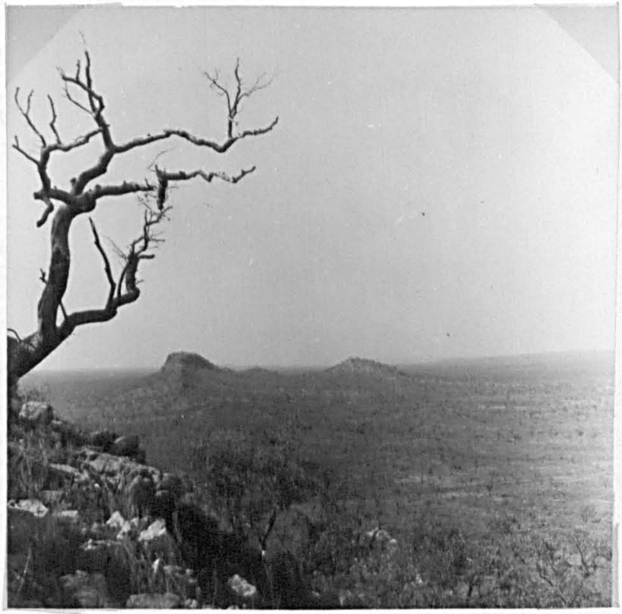
In the Turkey Creek Area, (Fig. 2), about one mile south-east of the Little Eva Mine, malachite staining occurs in micaceous shales over a width of some 200 ft. and a length of over 1000 ft. Several smaller showings in similar rocks were noted south of this area, the largest being at Bedford Mine, where copper has been mined from shallow pits and shafts.

(4). Physiography

The present relief bears a close relationship to the geology. The main hill mass within the area is the prominent and rugged range of the Knapdale Quartzite, (Fig. 2). The range is about 10 miles long in a north-south direction and about 1 ½ miles in width, rising to between 200 and 300 ft. above the general level (Plate 2). The maximum elevation by Aneroid Barometer was 900

Plate I View along Mt. Rosebee fault zone, Dugald River Area

Plate 2 View towards Quartzite Range



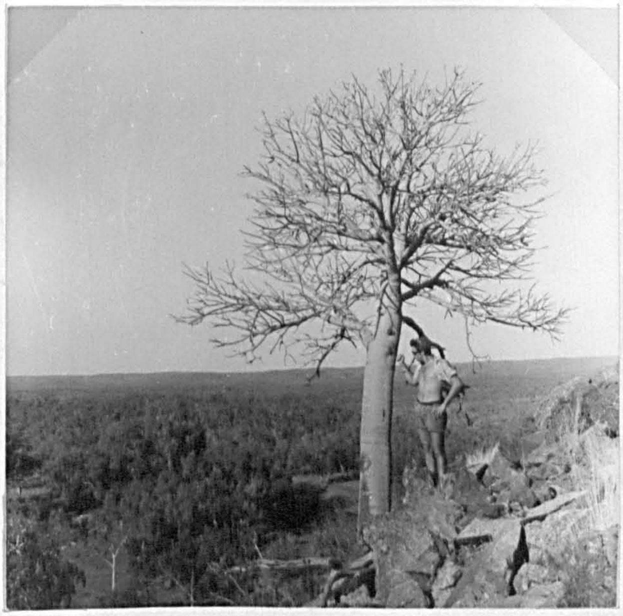


Plate I View along Mt. Rosebee fault zone, Dugald River Area

Plate 2 View towards Quartzite Range

ft. above sea level. Parallel to the Quartzite Range and a lower elevation lies the ridge of the Dugald River Lode Shales, rising to a maximum of 60 ft. above the general level. As the Lode shales lense out to the north and south, this ridge is replaced by parallel ridges composed of argillaceous limestones and fragmental calc-silicates.

The ground between the Quartzite Range and the Lode Ridge is relatively flat, with a cover of a variable depth of sheet wash alluvium, (Figs. 4 A and B). Where the larger creeks traverse this vale they have developed terraces covered by coarse alluvium derived from the Quartzite Range to the west. The main drainage direction is from west to east in the Lode Area, i.e. transverse to the regional strike, though several of the larger tributaries have cut back along the outcrop of the less resistant rocks.

The Lode Ridge gives way eastwards to a more or less uniform plain,interrupted in places by ridges of the more siliceous rock types, such as the fragmental calc-silicates. The level interfluves are covered by a thin veneer of sheet wash alluvium. Further east again the ground rises in a series of low hills to the second main area of upland topography. This comprises a series of north-south trending ridges of which the highest, Mt. Rosebee, rises to about 840 ft. above sea level., (Plate 1).

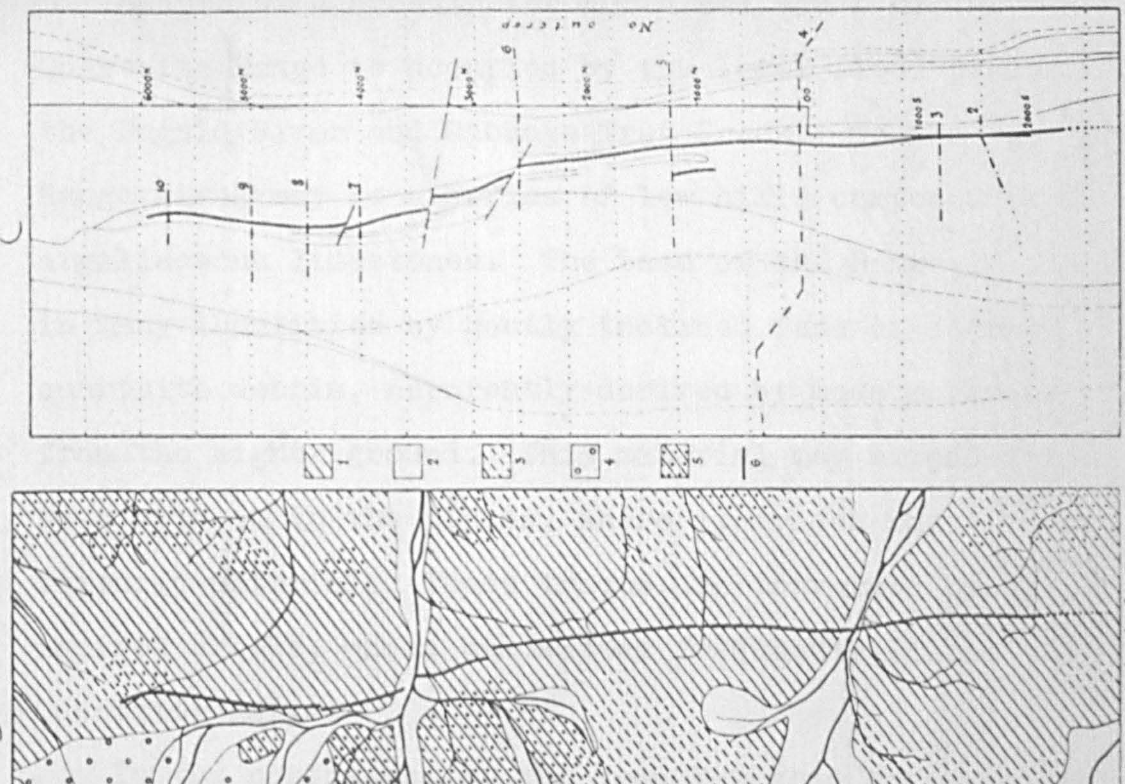


Fig. 4 A,B,C Maps of the Dugald River Lode Area, showing Topography, Overburden, and Location of Botanical Transects and Geochemical Traverses

Much of the area to the north and south of the Quartzite Range is occupied by the level flood plains of the Dugald River and Cabbage Tree Creek. To the west the Range gives way to a series of low hills composed of argillaceous limestones. The base of the Range is flanked in many localities by gently inclined fans of coarse quartzite debris, apparently derived by mass movement from the higher ground. This material may extend for up to a mile on to the plains, where it grades into finer-textured material. These tracts are traversed by deeply-incised creeks, whose headwaters frequently lie in the Quartzite Range.

In the north-east of the area Mesozoic rocks outcrop in a small mesa, with an elevation of about 630 ft. above sea level and 100 ft. above the surrounding plain.

The major rivers, i.e. the Dugald River and Cabbage Tree Creek, drain from south-west to north-east. Flow is restricted to the wet season and, although scattered water holes may be found at low points in the river beds, few of these survive the dry season. The rivers, in common with the major creeks, are deeply incised. Flood plains up to a mile in width have been developed where the rivers traverse less resistant rocks.

(5). Evolution of the landscape

It is probable that the area lay near the edge of the basin of sedimentation during the Cretaceous period, as witnessed by the coarse clastic nature of the rocks of this era within the region. The flat-lying disposition of the sediments, and the fact that the summit of the Mesozoic Mesa lies below that of the Quartzite Range, suggest that, unless faulting be presumed, the latter formed a promontory into the deposition basin.

At the close of sedimentation the area was uplifted and the widespread Australian pediplain of King, (1949), was formed. This has been variously dated as probably Miocene by Stewart, (in Christian and Stewart, 1953) and Pliocene by Whitehouse, (1941). In the Dugald River Area, erosion has destroyed much of the surface, but it is still preserved on the summit of the Mesozoic Mesa, the Quartzite Range and Mount Rosebee (Plates 1, 2). The major rivers of the area, the Dugald River and the Cabbage Tree Creek, were probably initiated on this surface. They flow south-west to north-east, i.e., diagonally across the strike of the geology and the main physical features.

Lateritisation is associated with this surface in many parts of Australia. Laterite is still preserved on the summit of the Mesozoic Mesa, but it has apparently been removed from the other regions of higher country by subsequent erosion. In the case of the Quartzite Range, however, the following observations may testify to its former occurrence :

A. Laterite nodules were found in fine stream alluvium near the western edge of the Range.

B. Deposits of quartzite rubble up to 12 ft. thick and cemented by a ferruginous cement were noted at several localities near the north end of the Range, (Plate 4).

At one point, this type of deposit extended across a stream channel within the Range, but generally they were developed at the foot of the higher ground opposite valley mouths. They have been breached by the present day streams, suggesting that they have at least an early Recent age. It seems quite probable that the iron oxides with which the deposits are cemented have been derived by solution of a lateritic crust on the summit of the Range, and subsequent re-deposition in the stretches of rubble at the base.

As previously mentioned, erosion has destroyed the bulk of the Australian pediplain. As the rivers reached the new base level, they deposited the extensive tracts of flood plain alluvium which now border their courses over much of their length. This alluvium generally consists of fine sands and silts, but stretches of fine grey clay near Cabbage Tree Creek also seem to have a fluviatile or lacustrine origin. These now generally lie at some distance from the river and separated from

Plate 3 Mesozoic sandstones in bank of Cabbage Tree Creek

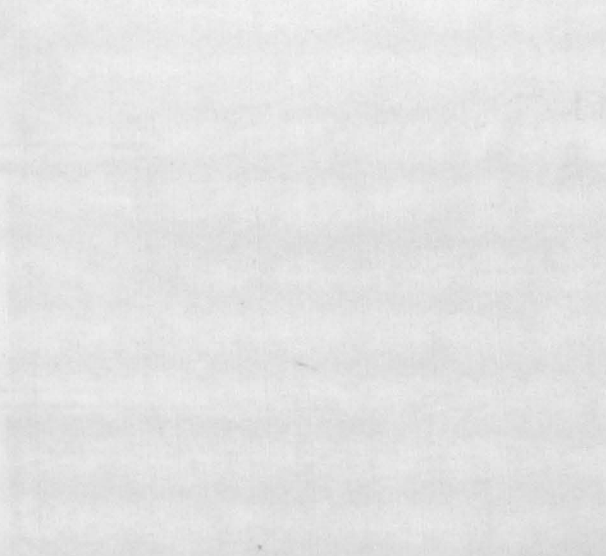


Plate 4 Cemented Quartzite rubble at north end of Quartzite Range

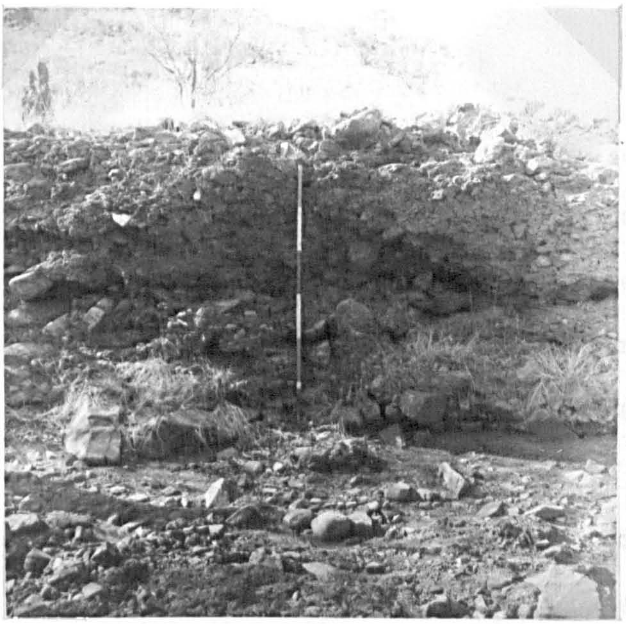


Plate 3 Mesozoic sandstones in bank of Cabbage Tree Creek

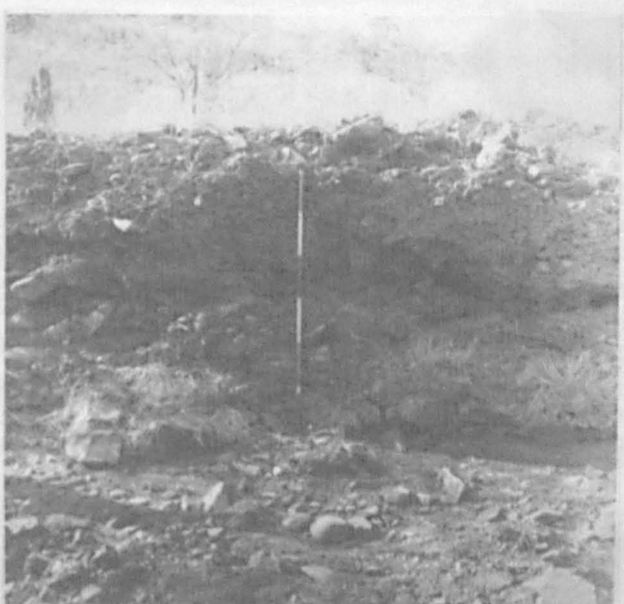


Plate 4 Cemented Quartzite rubble at north end of Quartzite Range

it by levee and flood plain material. It is suggested that they represent the sites of former swamps or lakes, which became cut off from the river by the formation of levees; during periods of flood, the river overflowed its banks, depositing fine clay which gradually filled the depressions.

Following on this period of dominantly fluviatile erosion and deposition, or possibly in part contemporaneous with it, more arid conditions seem to have set in which have persisted more or less to the present, (c.f. Whitehouse, 1940). In places the landscape shows many features indicative of pediplanation. The steep-sided nature of the Quartzite Range and other residuals, the spreads of alluvium at their base, (grading from coarse rubble to fine loam with distance), testify to sheet wash erosion as the dominant force. In places, quartzite rubble has been found up to a mile from the foot of the Quartzite Range and well away from any creek which might have carried it there. In other areas, the overlying detritus has been removed by recent erosion, exposing the gently-sloping pediments which have been carved in the underlying rock.

Recently there would appear to have been a second, minor, drop in base level, (which has exposed extensive areas of coastal alluvium on the Gulf of Carpentaria - Stewart, ibid). Many of the creeks and rivers show deep incision, the banks of Cabbage Tree Creek and the Dugald River commonly being 15 to 20 ft. in height, (Plate 3). Parts of the region have been deeply dissected by the smaller creeks, e.g. the extensive area of calc-silicates surrounding Mount Rosebee. As mentioned above, current erosion is also removing the colluvial material flanking the Quartzite Range. Many of the creeks are bordered by terraces, suggesting fluctuations in base level, either on a local or regional scale.

(6). Soils

(a). Introduction

Five major soil types have been recognised in the Dugald River Area. These have been named after the classification by Stephens, (1962). They comprise Skeletal Soils, Grey Calcareous Soils, Arid Red Earth Soils, Grey Soils of Heavy Texture and Levee Soils, (Table 3). In addition, remnants of former lateritic profiles occur within the region, but these are of limited distribution.

The soils being formed in the area at the present day are all characterised by a lack of any well-defined textural differentiation. Generally speaking there is a decrease in the grain size with depth, due to the eluviation of the finer clay material, but this has not reached the stage where distinct horizons have been developed. The majority of the soils, however, show a zone of lime accumulation - the calcrete layer - near the base of the profile. In one profile through an Arid Red Earth, an iron hardpan had been developed. These horizons probably indicate solution of the lime and iron in rainwater and their subsequent re-deposition at the contact with the bedrock surface.

The distribution of the soils is largely governed by the relief and by the geomorphological processes acting on the landscape. Skeletal and Grey Calcareous Soils are largely restricted to areas of intermediate to high elevation, the latter type occurring on the calcareous varieties of the calc-silicate rocks. The Arid Red Earths are found on the level interfluves lying between the upland country and the flood plains of the major rivers. In many areas a thick deposit of coarse colluvium occurs between the base of the higher ground and the areas occupied by these soils. The latter have thus apparently been derived from alluvial material eroded off the neighbouring upland region, probably by processes akin to sheet wash action.

Parts of the wide flood plains of Cabbage Tree Creek in the north of the study-area are occupied by the Grey Soils of Heavy Texture. These soils appear to have been developed from fine-textured alluvium, probably deposited in swamps or lakes bordering the creek and separated from it by the levees. The latter consist of deep yellowish-

Table 3 : Summarised Characteristics of the Soils of the Dugald River Area.

Soil Type	Profile	Occurrence	Vegetation
Skeletal Soils	Mostly shallow, gravelly soils, with no profile development	Generally on upland country	Eucalyptus spp., Triodia pungens with and without Acacia chisholmi
Grey Calcareous Soils	Deep, grey, very calcareous soils, passing downwards into rotted bedrock	Areas of intermediate elevation, underlain by calc-silicates	Eucalyptus argillacea, E. terminalis, Acacia chisholmi, Triodia pungens
Arid Red Earth Soils	Reddish soils with high proportion of clay throughout the profile - calcrete horizon common at base	Level interfluves at low elevations	Eucalyptus argillacea, E. terminalis Carissa lanceolata, Sporobolus australasicus
Grey Soils of Heavy Texture	Deep clay soils with little profile development, apart from zone of calcrete at base	Low-lying ground on flood plain of Cabbage Tree Creek	Astrebla pectinata, Iseilema macrathera
Levee Soils	Deep, yellowish-red, fine textured soils, increasing lime content with depth	Flanking the major rivers	Variable, but Eucalyptus argillacea, E. terminalis Acacia chisholmi & Sporobolus australasicus all common

red fine sands and silts. Some movement of lime has occurred within the material, and they have therefore warranted the name Levee Soils.

(b). Description of the major soil types

(i). Skeletal Soils

Skeletal Soils are found on ridges and other areas undergoing current dissection where erosion prevents the formation of a deep soil cover.

The soils are generally fairly shallow, ranging from a few inches on the harder, more siliceous rocks to two or three feet in the more easily weathered shales and calc-silicates. A large percentage of the soil is comprised of stone fragments derived from the underlying parent material.

As the name implies, little or no textural differentiation has taken place, though in some profiles there is an increase with depth in the clay content of the interstitial material. The soils are generally reddish in colour, sometimes becoming a deeper colour near the base of the profile, presumably due to eluviation of iron. The soil reaction depends on the parent rock; it is acid to neutral on shales, quartzites, etc., and basic when developed on limestones and the more calcareous calc-silicates.

Profile 1 is an example of a skeletal soil developed on shales.

Profile 1. Gently sloping gravelly ground with outcrops of dark grey micaceous shales; the vegetation consists of *Eucalyptus brevifolia* F. Muell., *Triodia pungens* R.Br. and *Cleome viscosa* L.

Profile Description

0 - 12ins.:-	Dusky red 2.5 YR 3/2 stony micaceous sand, with abundant shale fragments up to 1 by 1½ ins. pH 5.6.
12 - 22ins.:-	Dark reddish brown 5 YR 3/2 stony micaceous sand with abundant shale fragments as above. pH 5.8.
22 - 30ins.:-	Dark reddish brown 5 YR 3/2 stony clay, with abundant shale fragments. pH 6.1.

(ii). Grey Calcareous Soils

These have developed on the more calcareous calc-silicate type rocks, in areas sheltered from strong erosion. In these situations, they may reach depths of up to 5 ft.

The soil consists of very calcareous, nodular material passing down into decomposing parent material. The dominant colour is grey or pink, though admixture of organic matter or iron oxides may produce dark grey or reddish surface horizons.

The reaction is basic, (pH from 7.4 to 8.0), and increases with depth. No textural differentiation has taken place, apart from some clay eluviation.

Like the last type, these soils are relatively young in age, and have been produced by weathering of the calc-silicate parent material.

Profile 38, (Plate 5), is a good illustration of this soil type.

Profile 38. The profile is situated on gently sloping ground on a low interfluve; the vegetation consists of E. terminalis F. Muell., Acacia chisholmi F.M. Bailley, Triodia pungens, Cleome viscosa and Sporobolus australasicus Domin.

Profile Description

0 - 14ins.:- Dark greyish brown 10 YR 4/2 silty clay with abundant white calcrete nodules up to 2 x 3 ins.; the nodules make up approximately 50% of the whole, and tend to lie with their long axes horizontal, giving a rough stratification. pH 7.4.

14 - 26ins:- Pale brown 10 YR 6/3 clay, with gritty texture due to calcrete; nodules of same size as above; very calcareous. pH 7.8.

26 - 53ins.:- Pinkish grey 7.5 YR 6/2 clay, with gritty texture due to calcrete fragments; large fragments of decomposing rock are

Skeletal Soil on Shales

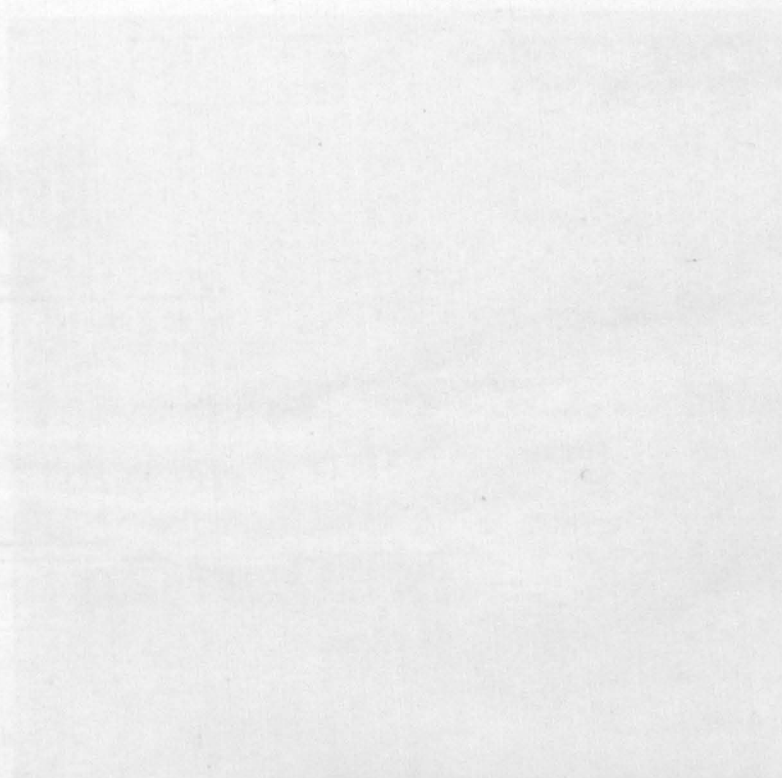
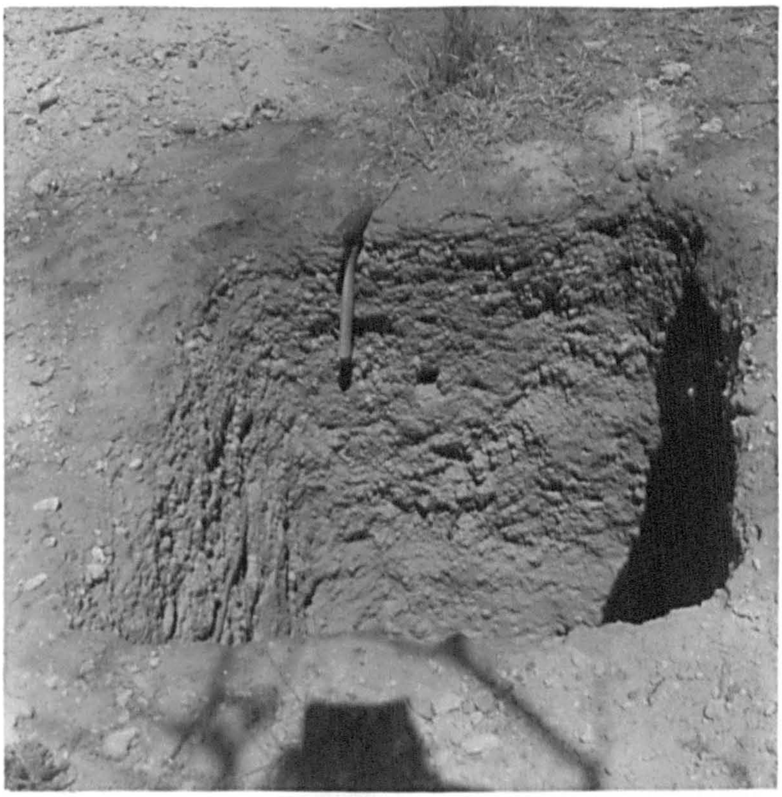


Plate 5 Profile through Grey Calcareous Soil



Skeletal Soil on Shales

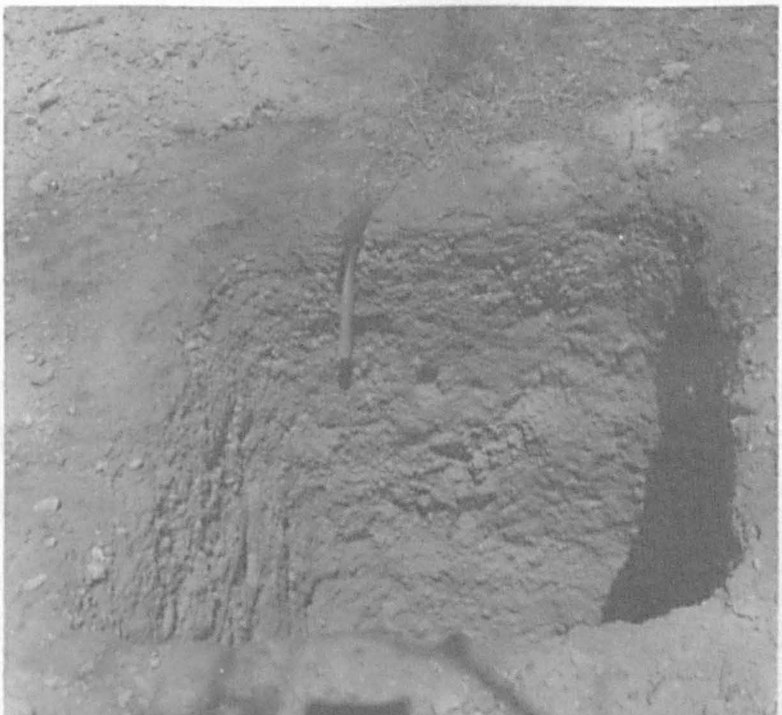


Plate 5 Profile through Grey Calcareous Soil

present, surrounded by and made over to calcrete; very calcareous . pH 8.0.

(iii). Arid Red Earths

This soil type is quite common, developing on the interfluvial tracts at lower elevations. As implied by the name, the soils have a characteristic reddish colour, ranging from a dark reddish brown at the surface to dark red at depth.

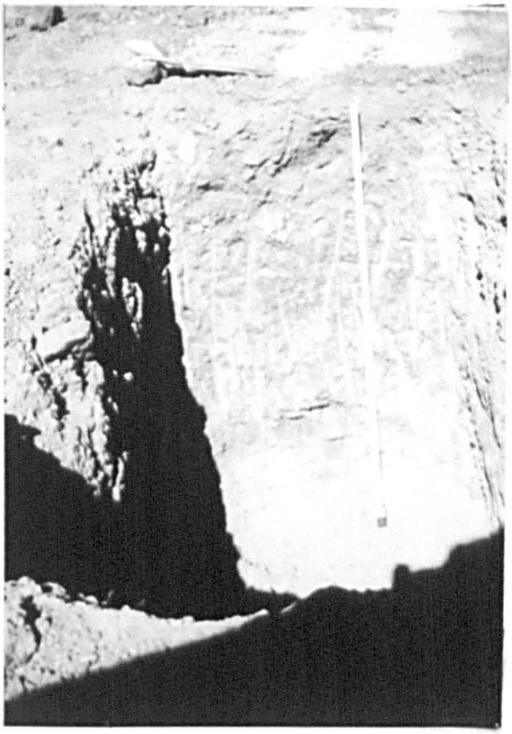
The depth varies between 2 and 4 feet, and, as in the above types, shows little variation in texture apart from a general decrease in grain size with depth. Thus the surface few inches is generally of sandy to sandy clay loam texture, frequently with grit and gravel deposited by surface wash. This passes down into a compact structureless clay which grades into weathered bedrock at the base. Lenses and masses of calcrete are generally present above the bedrock surface, and, in one profile, a thin iron hardpan was found at the same level. In thin section, this was seen to consist essentially of rounded to sub-rounded quartz crystals and small flakes of muscovite in a dense haematite matrix. This zone was bounded above and below by fine laminated earthy material with limonitic staining.

Rock fragments from grit to gravel size occur throughout the soil profile: in some cases, these are of the same lithology as the underlying bedrock, while in others there is an admixture of several different rock types. The soil reaction ranges from acid at the surface (pH from 5.0 to 6.4) to slightly acid to basic at depth (pH from 6.4 to 7.7).

It appears that these soils may form from different parent materials. In some cases, the occurrence of rock fragments throughout the profile of the same lithology as the underlying bedrock points to a residual origin. In other cases, the admixture of several rock types in the upper horizons suggests derivation from alluvial material. This has probably been deposited by sheet wash action; the low interfluves on which these soils are frequently developed grade laterally and upslope into gently inclined fans of rubble and gravel, spreading out from the bases of the higher hills and ranges.

As regards the zones of lime and, occasionally, iron and silica accumulation, these have presumably been formed by downward leaching and re-deposition by rain-water. Stephens,(1962),considers that this soil type is probably polygenetic, representing red earths formed in a wetter climatic era and later invaded by calcium carbonate. He suggests that the latter could be derived from loessial additions, temporary invasion of the profile by ground water or, less probably, continued weathering of soil material and accumulation of lime under the prevailing arid conditions.

Plate 6 Profile through Arid Red Earth Soil, with hardpan and calcrete horizons



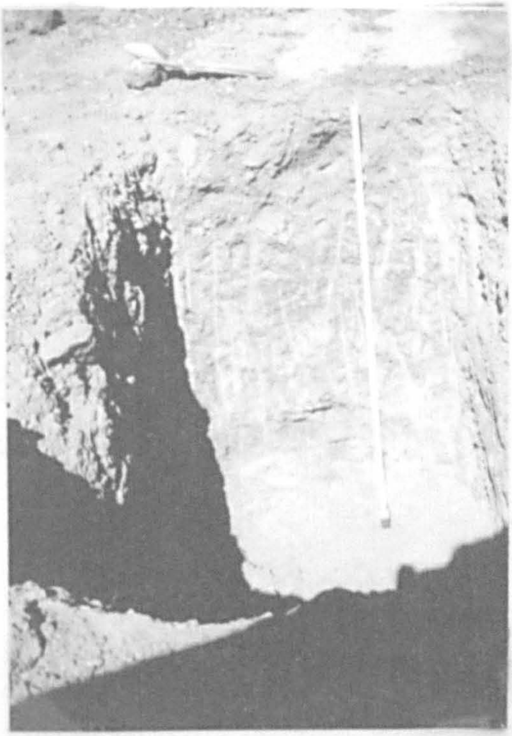


Plate 6 Profile through Arid Red Earth Soil, with hardpan and calcrete horizons

Profile 21, (Plate 6), illustrates the main features of the residual type of Arid Red Earth with, however, the development of a hardpan, while Profile 44 is apparently derived from alluvial material.

Profile 21. Level ground, gravelly to sandy surface, with scattered outcrops of dark grey spotted calcareous siltstones. The vegetation is very open, comprising scattered *Eucalyptus argillacea* W.V. Fitz and *E. papuana* F. Muell. and the shrubs *Eremophila mitchellii* Benth and *Carissa lanceolata* R.Br. with *Triodia pungens*, *Sporobolus australasicus* and *Gomphrena brownii* Moq.

Profile Description

0 - 11ins.:-	Dark reddish brown 2.5 YR 3/4 slightly micaceous sand with a little clay, with angular fragments up to 2 by 5 ins. of calcareous siltstone similar to the bedrock. pH 6.4.
11 - 18ins.:-	Dark red 2.5 YR 3/6 clay with occasional fragments of calcareous siltstone.
18 - 26ins.:-	Same matrix as above, but with small angular fragments of spotted calcareous siltstone: in this horizon, however, the spots are much paler and the fragments are frequently vertical or sub-vertical. pH 6.8.

26 - 42 ins.:- Masses and lenses up to 3 by 6 ins. of iron hardpan, frequently concretionary; generally sub-horizontal and discontinuous; lenses of calcrete are also quite common; both enclosed in a similar matrix to the above horizons. pH 7.0.

42 - 55 ins.:- Dark brown 7.5 YR 4/4 highly calcareous sandy clay, with fragments of spotted calcareous siltstone generally made over to calcrete. pH 7.6.

Profile 44. Near level gravelly and sandy ground; the area is very bare of vegetation, consisting of scattered *Eucalyptus papuana*, *E. terminalis* and *Atalaya hemiglauca* F. Muell., with the gravelly areas more or less devoid of ground cover, the sandier areas with sparse *Triodia pungens*, *Cleome viscosa* and *Sporobolus australasicus*.

Profile Description

0 - 4ins.:- Surface gravel and grit of quartz, quartzite and haematite, over dark reddish brown 5 YR 3/4 sandy clay with gravel as above. pH 6.0.

4 - 22ins.:- Dark reddish brown 5 YR 3/4 clay, with grit size fragments of same material as above. pH 6.2. (4 - 12 ins).: pH 7.1 (12 - 22 ins).

22 - 31ins.:- As above, but grit fragments more common pH 7.3.

31 - 39ins.:- Dark red 2.5 YR 3/6, clay with small calcrete blebs and quartz grains pH 7.4.

39 - 48ins.:- Gradation to rotted phyllites, with patches similar to the above horizon occurring along the bedding planes. pH 7.6.

(iv). Grey Soils of Heavy Texture

This soil type is restricted to low-lying tracts bordering the levees and flood plains of Cabbage Tree Creek in the north of the area.

The soil surface exhibits a series of low hummocks and depressions. Little horizon development has taken place, the profile consisting of several feet of grey clay penetrated by deep vertical cracks up to one or two inches across. Small grit-sized rock fragments are scattered throughout the profile; these have probably been washed down the cracks from the surrounding higher ground during periods of heavy rain.

At the base, there is a sudden change to weathered rock with a layer of calcrete immediately above. Apart from the surface material, the soil reaction is basic throughout.

There seems little doubt that the soils have been developed from fine clay alluvium deposited from the adjacent river. This is suggested by their situation, on low-lying country subject to flooding, their lack of textural differentiation and their sharp junction with the bedrock below.

A similar derivation has been suggested for this soil type in the Barkly Region, (Christian et al 1954).

Profile 35, (Plate 7), is taken through such a soil; it is situated on the south bank of Cabbage Tree Creek near Little Eva.

Profile 35. General relief level, but micro-relief consists of a series of hummocks and depressions, average height from depression to crest 6 ins., 2 to 3 feet apart. The vegetation includes Astrebla pectinata (Lindl.) F. Muell., Iseilema macrathera Domin. with Ocimium sanctum L., Crotalaria trifoliastrum Willd, Hibiscus trionum L., Ipomoea lonchophylla J.M. Black, Neptunia gracilis Benth, Euphorbia uhligiana Pax.

Profile Description

0 - 48 ins.:- Greyish brown 10 YR 3/2 heavy clay, with scattered grit-sized fragments of pink-coloured rock, (? calc-silicates), scattered throughout; some horizontal foliation present; deep cracks, up to 2 ins. across, extend to 3 ft. depth; small calcrete

Grey Soils of Heavy Texture near Little Eva

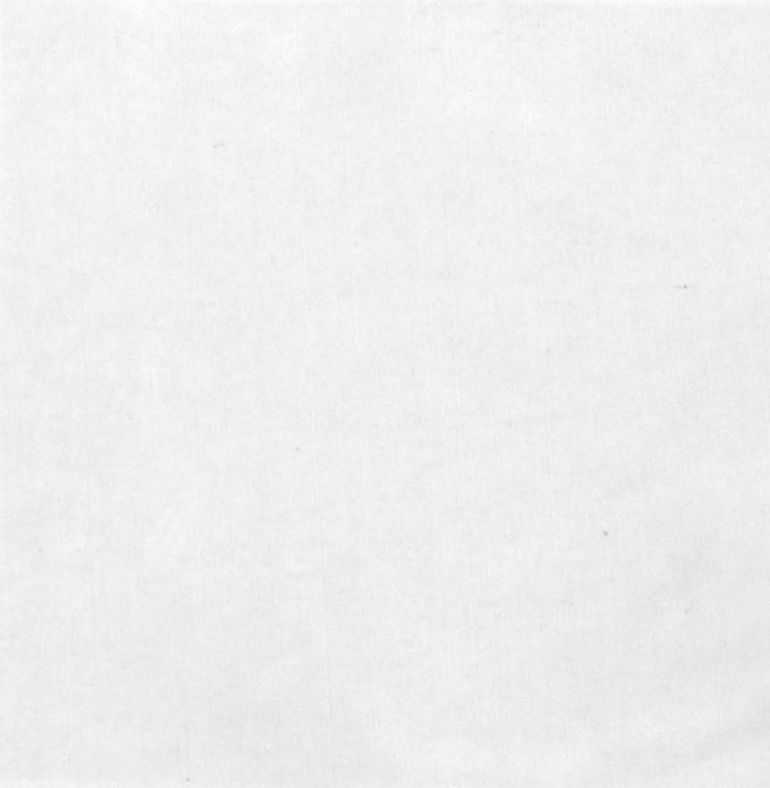
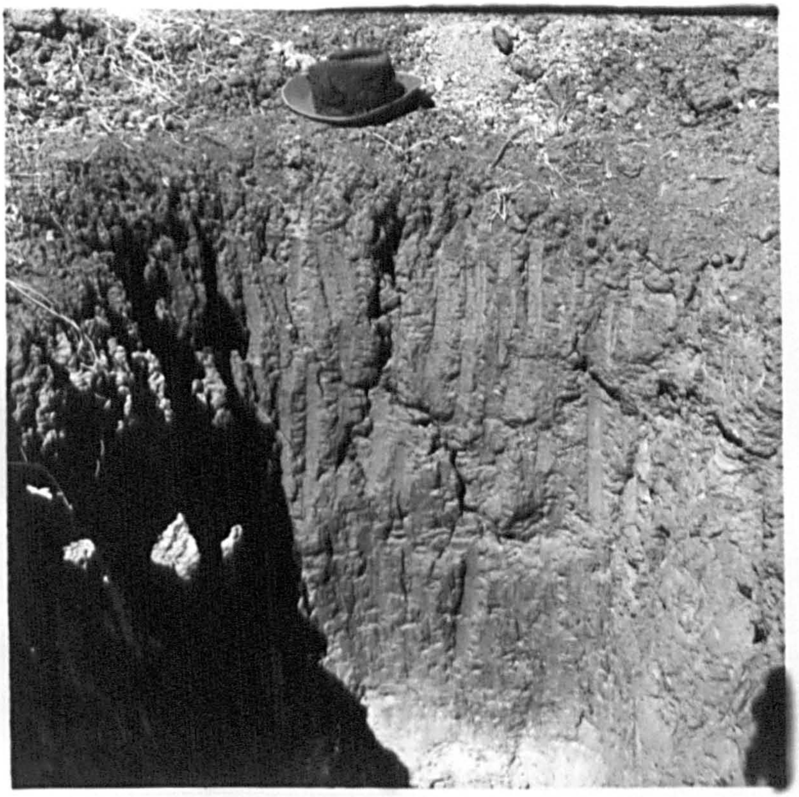


Plate 7 Profile through a Grey Soil of Heavy Texture



Grey Soils of Heavy Texture near Little Eva

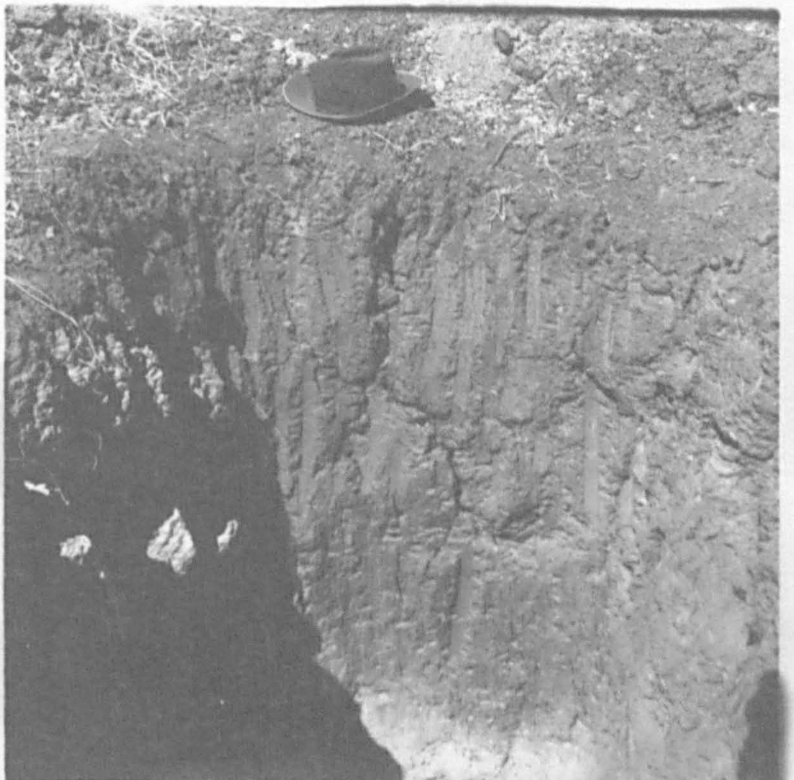


Plate 7 Profile through a Grey Soil of Heavy Texture

nodules, 1/10 inch across, are present and become more common with depth.

Surface material. pH 6.8.

0 - 6 ins. pH 7.4.

24 - 36 ins. pH 7.4.

48 - 52 ins.:- Change to (pH 7.2.)

52 - 70 ins.:- Granular decomposing rock, with abundant calcareous material and veinlets of calcite; no apparent change with depth.

52 - 58 ins. pH 8.2.

60 - 70 ins. pH 7.8.

(v). <u>Levee Soils</u>

These soils are restricted in occurrence to the levees bordering the major rivers of the area.

Several profiles were sunk in the levee near Little Eva on the south bank of Cabbage Tree Creek. A dark reddish brown surface horizon gives way to a yellowish red colour at depth. The texture is clayey, sandy or silty, but little textural differentiation has occurred apart from a slight decrease in grain size with depth. The pH of the soil increases from around 6.7 at the surface to 8.0 at the greatest depth reached (14 ft.): this agrees with the appearance of calcrete nodules some way down the profile. Occasional subangular fragments of quartz and calc-silicate rock are present throughout.

Profile 34 is situated on typical levee material.

Profile 34. The profile is situated on a gentle slope to the south: the vegetation consists of an open tree cover by *Eucalyptus argillacea*, with ground vegetation of *Sporobolus australasicus*, *Aristida browniana* Henrard, *Perotis rara* R.Br., *Breweria media* R.Br. with scattered *Cleome viscosa* and patches of *Triodia pungens*; by inference from outcrops to south, the profile is located on calc-silicates.

Profile Description

Pit extends to 84 ins.; thereafter, information from auger hole.

0 - 6 ins.:- Dark reddish brown 5 YR 3/3 fine micaceous sand with organic matter; non-calcareous. pH 6.8.

6 - 42 ins.:- Reddish brown 5 YR 4/4 loamy micaceous sand with occasional subangular fragments of quartz and ? calc-silicate rock; non-calcareous, structureless. pH 6.6.

42 - 72 ins.:- Yellowish red 5 YR 4/6 loamy sand, with some pockets of lighter coloured material at base; these have possibly been formed by eluviation of iron. pH 6.9.

72 -129 ins.:-	Same material as above, but with scattered calcrete nodules, apparently concentrated into layers; calcareous pH 7.6.
129 -167 ins.:-	Yellowish red 5 YR 4/6 fine silty micaceous sand; with scattered calcrete nodules becoming more common near the base; the interiors of the nodules show a rough crystalline structure. 129 - 144 ins. pH 8.0. 144 - 167 ins. pH 8.0. Hole bottoms at 167 inches.

(7). <u>The major and trace element status of the soils</u>

(a). <u>Introduction</u>

A range of surface soil samples, representing all the major soil types occurring within the Dugald River Area, have been analysed for various major and trace elements.

The objective of the study was to investigate whether there was any correlation between the variation in the concentration of these elements in the surface soil horizons and the distribution of the major soil types and vegetation associations within the region. In addition, by comparison of the results of this investigation with those in other semi-arid regions of Australia, it was hoped to gain a rough estimate of the general level of fertility of the soils of the Dugald River Area.

The elements carbon, nitrogen, phosphorus, potassium and sodium were analysed by normal chemical methods, while magnesium, iron, manganese, cobalt, copper, lead and molybdenum were determined on an Arc Emission Spectrograph. Details of the analytical methods are indicated in Appendix A.

Some points should be made on the presentation of the results, (Table 4). Grouping of the samples has been made firstly on the basis of the major vegetation associations, and secondly on the basis of the soil types. The association which is most frequent on regions of fairly high relief has been placed at the top of the table. Thereafter, the order of presentation follows roughly on that of decreasing elevation and increasing depth and clay content of the soils. Those samples from areas of lead-zinc or copper mineralisation, regions where the normal balance of the elements in the soil is greatly disturbed, have been placed in a separate grouping at the foot of the table.

(b). Discussion of the results

The majority of the samples have a soil reaction varying between slightly acid to neutral. Skeletal soils derived from the quartzites and shales, and the Arid Red

Table 4 : Chemical and spectrographic Analysis of Near-Surface Soils from the Dugald River Area.

Method of Analysis				Electro-metric	Chemical							Arc Emission Spectrography					
								HCL-extractable									
Vegetation	Soil	No.	Depth-inches	PH	Organic C %	Total N %	C:N Ratio	P ppm	K %	Na ppm	Mg %	Fe %	Mn ppm	Co ppm	Cu ppm	Pb ppm	Mo ppm
Eucalyptus brevifolia - Triodia pungens	Skeletal Soil on Quartzite	7127	0- 8	6.0	0.285	0.013	21.1	80	0.11	75	0.26	7.4	900	10	10	0	0
		7733	4- 6	5.8	0.321	0.017	18.1	230	0.63	-	0.68	9.0	2100	10	10	0	0
	Skeletal Soil on Shales	11	0-12	6.1	-	-	-	830	0.70	-	1.00	10.0	850	20	125	1100	0
		16	0-10	6.0	x	0.015	-	470	0.40	-	0.29	4.4	540	15	200	T	0
		34	0-11	6.6	x	0.019	-	550	0.38	-	0.38	8.0	600	18	210	0	T
	Skeletal Soil on Calc-silicates	87	0- 6	5.6	0.391	0.027	14.3	160	0.16	-	0.21	5.6	320	18	1200	0	0
		178	0- 6	5.6	0.123	0.007	16.2	120	0.07	-	0	5.2	1750	0	230	0	0
		211	0- 6	6.4	0.336	0.022	15.4	260	0.43	-	0.72	9.0	1550	16	10	0	0
		212	0- 6	6.0	0.282	0.018	15.3	200	0.78	60	0.76	10.0	670	25	90	0	0
Eucalyptus argillacea - E. terminalis - Acacia chisholmi - Triodia pungens	Skeletal Soil on Shales	195	0- 6	6.2	-	-	-	490	0.42	80	0.61	7.0	3400	12	100	T	0
		180	0- 6	6.4	x	0.031	-	520	0.45	-	0.74	10.0	1900	20	270	0	T
	Skeletal Soil on Calc-silicates	228	0- 6	7.8	0.329	0.026	12.7	320	0.19	-	0.83	6.4	650	18	150	0	0
		223	0- 6	7.0	0.439	0.030	14.7	390	0.21	-	0.60	10.0	520	24	72	0	0
	Grey calcareous Soil	30	0-10	7.6	x	0.006	-	185	0.42	725	1.55	3.2	1150	15	52	290	0
		237	0-10	7.6	0.348	0.024	14.7	290	0.16	225	0.64	10.0	220	10	10	0	0
		233	0-14	7.4	1.161	0.072	16.0	190	0.09	-	3.60	4.6	560	10	105	0	0
	Skeletal Soil on Limestones	28	0-24	6.4	x	0.018	-	690	0.87	255	1.10	10.0	2900	42	510	825	T
		176	0- 6	6.5	x	0.010	-	750	0.78	-	1.30	8.0	740	22	110	2200	0
		192	0- 6	7.6	x	0.044	-	295	0.48	-	2.00	8.0	2600	17	58	0	0
		193	0- 6	7.4	-	-	-	590	0.69	-	1.40	10.0	1700	22	280	640	0

Vegetation	Soil	No.	Depth-inches	PH	Organic C %	Total N %	C:N Ratio	P ppm	K %	Na ppm	Mg %	Fe %	Mn ppm	Co ppm	Cu ppm	Pb ppm	Mo ppm
Eucalyptus argillacea	Arid Red Earths	59	0- 8	5.7	0.379	0.037	10.3	190	0.43	80	0.33	6.0	700	18	100	0	0
		4	0- 4	6.9	0.585	0.043	13.7	170	0.56	-	0.64	6.4	950	10	64	0	0
E. terminalis-		39	0- 6	6.4	0.257	0.027	9.6	130	0.39	150	0.41	9.0	1200	10	165	0	T
Carissa lanceolata -		61	0-12	6.4	0.269	0.020	13.6	180	0.25	65	0.24	5.6	650	17	180	0	0
Sporobolus australasicus	Levee Soil	246	0- 5	7.1	0.430	0.029	14.9	320	0.37	-	1.25	10.0	1100	18	90	0	0
Acacia cambagei	Grey Calcareous Soil	242	0- 3	7.2	0.542	0.048	11.32	390	0.36	-	0.37	5.2	620	18	300	0	0
	Lateritised Shales	1718	2- 3	5.4	-	-	-	30	0.07	290	0.23	10.0	1200	20	150	T	T
Astrebla pectinata- Iseilema macrathera	Grey Soil of Heavy Texture	81	0- 6	7.4	0.421	0.023	18.5	85	0.44	420	0.55	4.6	520	25	600	0	0
Eriachne mucronata - Polycarpaea glabra -	Skeletal Soils on Graphitic Shales	26	0-11	6.2	-	-	-	1000	0.93	90	1.30	10.0	4000	20	270	1000	0
		175	0- 6	5.6	x	0.028	-	960	0.80	-	1.20	10.0	1900	10	72	1400	T
		194	0- 6	6.1	-	-	-	600	0.21	-	0.33	8.0	600	0	190	800	0
Bulbostylis barbata	Skeletal Soils on Pb/Zn Lode	9	0-12	6.1	x	0.034	-	1500	0.27	130	0.40	10.0	2200	25	1200	8000	0
Polycarpaea glabra - Tephrosia sp.nov. (Dugald River No. 5)	Skeletal Soils on Copper-bearing Shales	232	0- 6	5.8	0.511	0.039	13.1	550	0.58	-	1.50	10.0	5000	23	7000	0	0
		225	0- 6	5.7	0.458	0.030	15.4	1300	0.41	140	1.05	10.0	4000	20	10,000	0	0

x : Samples with anomalous values for carbon, suggestive of inclusion of graphite or charcoal
T : Trace
- : Not determined

Earths, are almost invariably acid, as are those from areas containing mineralisation. The soils developed from calc-silicate rocks range between acid and basic, depending on the nature of the parent rock. Where this is siliceous, with a large proportion of quartzitic inclusions, the resulting soils are acid, whereas the softer, more calcareous varieties give rise to basic soils. The soils derived from limestones, the Grey Calcareous Soils and the Grey Soils of Heavy Texture are generally basic on the surface.

There is a fairly close correlation between the distribution of the Eucalyptus brevifolia - Triodia pungens and Eucalyptus argillacea - E. terminalis - Acacia chisholmi - Triodia pungens associations and the pH of the soil. The former is much more widespread on soils with acid surface reactions, while the latter shows a tendency to occur on soils where the surface reaction is basic. Thus the respective ranges in pH values for the samples analysed are 5.6 to 6.6 and 6.2 to 7.8.

Some difficulty was encountered in the determination of organic carbon in some of the samples, (marked with an asterisk in Table 4). This was particularly the case in those soils developed on shales or limestones, or from areas where the vegetation had been recently burned-off, where anomalous results suggested inclusion of elemental organic carbon, such as graphite or charcoal.

The results for the remaining samples show little precise correlation with soil type or variations in the vegetative cover, though there is a tendency towards lower values in the samples from areas occupied by the Eucalyptus brevifolia - Triodia pungens association. The highest concentration of organic carbon occurs in sample 233, where, however, the surface soil horizon showed a darkening, presumably due to the accumulation of organic matter.

The general level of organic carbon in the soils of the Dugald River Area is of the same order as that found by Jackson, (1962), in his study of the soils of the Alice Springs region of central Australia. Likewise, the values obtained in the present study compare favourably with those of Beadle and Tchan, (1955), in their investigation of the soils of semi-arid plant communities in New South Wales. Comparison with the level of organic carbon quoted by Williams and Steinberg, (1958), for the soils of the Brisbane region, however, indicates that the soils of the Dugald River Area are low in this element.

The results for total nitrogen also show little relationship to variations in the soil type or vegetative cover, though again there is a suggestion that the soils occupied by the Eucalyptus brevifolia - Triodia pungens associations are low in this element. The higher values cannot be correlated with the distribution of the leguminous trees or shrubs, Acacia cambagei R.T. Baker and A. chisholmi, which may suggest that these species are not associated with nitrogen fixation.

Compared with the results obtained by Williams and Steinberg, (ibid), and Beadle and Tchan, (ibid), the soils of the Dugald River Area are very low in nitrogen. The former authors ~~quotes~~ quote a mean value of 0.128% nitrogen, which is approximately twice that of the highest value found in the present study.

Variations in the ratio of carbon to nitrogen shows a closer relationship to changes in the soil type or vegetative cover than those of the elements themselves. The soils occupied by the Eucalyptus brevifolia - Triodia pungens association, particularly those derived from quartzite, generally contain high carbon : nitrogen ratios. The soils underlying the Eucalyptus argillacea - E. terminalis - Acacia chisholmi - Triodia pungens association have intermediate values, while the samples from the Arid Red Earth soils, occupied by the E. argillacea - E. terminalis - Carissa lanceolata - Sporobolus australasicus association, contain low carbon : nitrogen ratios.

The values for the carbon : nitrogen ratios in the Dugald River soils are of the same order as those of Williams and Steinberg, (ibid), though, as mentioned above, the levels for carbon and nitrogen in this investigation were considerably higher than in the present one. The ratios are considerably higher than those obtained by Beadle and Tchan, (ibid), however.

The level of HCL-extractable phosphorus is generally highest in those soils developed on outcropping lead-zinc or copper mineralisation. The discrepancy between these results and the general level suggests that the phosphorus here may be derived from primary metallo- phospate minerals, such as libethenite ($4Cu\ P_2O_5\ H_2O$) and pyromorphite ($Pb_5Cl\ (PO_4)_3$), associated with the ore-deposits. The high values in some of the samples from soils derived from the shale and limestone horizons, which border the lead-zinc deposit, probably have a similar source. Since the mineralised rocks form a pronounced relief feature over the greater part of their outcrop, the erosional products from the deposit will be incorporated in the surface layers of the neighbouring soils at lower elevations.

Phosphorus is low in the sample from the Grey Soil of Heavy Texture, in the soil derived from lateritised shale, and in one of the samples from soils developed on quartzite. Otherwise, with the exception of the high values in the neighbourhood of mineralisation, there is little correlation with any particular group of soils.

Comparison of the results of this study with those of other investigations indicates little significant variation. The results are comparable with those of Beadle and Tchan, (ibid), who considered that, while phosphorus was low in the soils of their study-area, it was never a limiting factor in vegetation distribution. The low value obtained on the lateritised shales in the Dugald River Area, however, may have a bearing on the distribution of the associations. Though not restricted to these sites, Acacia cambagei is almost invariably found on the relics of lateritic soils within the region. It seems possible, therefore, that this tree, by virtue of a greater tolerance towards low levels of phosphorus, is capable of surviving on the lateritic soils while the other members of the tree stratum avoid them.

A similar explanation may account for the close correlation between the Astrebla pectinata - Iseilema macrathera grassland and the Grey Soils of Heavy Texture, where again the phosphorus content is low. In this case, however, the marked variation between the clay content of these soils and the surrounding material is probably a more important factor in vegetation distribution.

The soils of the Dugald River Area show a wide variation in the level of HCL-extractable potassium. The soil developed on the lateritised shale is again low in this element, though low values were also recorded from other sites. Otherwise, the distribution of potassium in the surface horizons shows little correlation with either the soil types or the vegetation associations.

HCL-extractable sodium shows a smaller range than potassium, the maximum values occurring in those soils with a comparatively high pH, such as the Grey Calcareous Soils and Grey Soils of Heavy Texture. The relatively low order of these values, however, suggests that the basic reaction in these soils is mainly due to calcium.

Some of the samples from the Grey Calcareous Soils, though not that from the Grey Soil of Heavy Texture, are also high in magnesium compared with the level elsewhere. There seems to be a general tendency for the soils occupied by the Eucalyptus argillacea - E. terminalis - Acacia chisholmi - Triodia pungens association to be richer in this element compared with the soils underlying the other vegetation associations, though some of the samples from the vicinity of mineralisation are also high. The soils of the Eucalyptus brevifolia - Triodia pungens and E. argillacea - E. terminalis - Carissa lanceolata - Sporobolus australasicus associations, on the other hand, gave relatively low results in general.

The values for iron in the soils of the Dugald River Area are of the same order as those obtained by Oertel and Giles, (1962), in their investigation of the trace element content of Queensland soils, (the location of their samples is not quoted). In the present study, high values occur throughout the majority of the various soil types and vegetation associations, though there is a tendency to lower results in the Grey Calcareous Soils and Grey Soils of Heavy Texture. This explains the light colour of these soils - elsewhere the soils are generally stained bright red due to inclusions of iron oxide.

The soils developed in the vicinity of mineralisation tend to be relatively high in manganese, presumably by derivation from the gossans occurring over some of the deposits. Broadly speaking, soils developed on calc-silicates, the Grey Calcarous Soils and the Arid Red Earths are poor in this element. The Grey Soil of Heavy Texture, occupied by the Astrebla pectinata - Iseilema macrathera association, is also low. On the whole, the values are higher than those obtained by Oertel and Giles, (ibid).

The results for cobalt show a comparatively small range of values and indicate that this metal is not associated with the ore-deposits occurring within the Dugald River Area. Comparison with the values obtained by Oertel and Giles, (ibid), shows that the level of cobalt is of the same order in the two studies. In the present area, no particular soil type or vegetation association is associated with high values of this element.

The presence of widespread copper mineralisation in the rocks of the Dugald River Area is reflected in the soil analyses. Neglecting the results from the vicinity of the ore-deposits, the general level is still considerably higher than that obtained by Oertel and Giles, (ibid), where the values rarely exceed 100 ppm. Within the present study-area low values are found in the soils derived from quartzite, but otherwise wide variations occur within each particular soil type. Apart from Polycarpaea glabra C.T. White and Tephrosia sp. nov., (Dugald River MMC/DMJP No. 5), species which are common over both lead-zinc and copper mineralisation within the area, no marked correlation is apparent between the distribution of the various vegetation types and the level of copper in the soils.

As would be expected, the higher values for lead occur in the soils developed on the lead-zinc lode and the bordering graphitic shales. The anomalous results for several of the samples from soils from un-mineralised shales and limestones are probably due to the inclusion of metal-rich particles, derived by erosion from the Lode, within the samples. Apart from these occurrences, lead is generally absent from the soils occurring within the region. Eriachne mucronata R.Br., Polycarpaea glabra and Bulbostylis barbata C.B. Clarke are associated with the zone of high lead content, but otherwise no correlation can be drawn between the variations in the vegetative cover and the distribution of this element.

Several of the samples, most frequently those from soils developed on shales, contain a trace of molybdenum, but apart from these the element is absent from the soils of the region

(c). Conclusions

(i). Soils derived from quartzites, shales and calc-silicates of the siliceous type, were acid on the surface, frequently showed comparatively high carbon : nitrogen ratios, and tended to be relatively low in carbon, nitrogen and magnesium. Areas occupied by these soils generally support the Eucalyptus brevifolia - Triodia pungens association.

(ii). The soils developed on the softer varieties of calc-silicates, limestones and the Grey Calcareous Soils, were generally basic on the surface, had carbon : nitrogen ratios of intermediate value, and were comparatively rich in magnesium. The Eucalyptus argillacea - E. terminalis - Acacia chisholmi - Triodia pungens association is normally developed on these soils.

(iii). The Arid Red Earth Soils, generally occupied by the Eucalyptus argillacea - E. terminalis - Carissa lanceolata - Sporobolus australasicus association, were acid on the surface, gave low carbon : nitrogen ratios, and showed a tendency to be relatively low in manganese and magnesium.

(iv). The distribution of the *Astrebla pectinata* - *Iseilema macrathera* association is restricted to those areas of Grey Soil of Heavy Texture. A sample of this soil had a relatively high carbon : nitrogen ratio, and was low in phosphorus, iron and manganese, but comparatively rich in sodium. These factors may have an influence on the distribution of this association, but it seems more probable that the marked contrast in clay content between these soils and the surrounding material is of more importance.

(v). A sample from an occurrence of lateritised shales, occupied by a stand of *Acacia cambagei*, was low in phosphorus and potassium compared with the level of these elements in the soil elsewhere within the area. This may have a bearing on the distribution of this species. It is almost invariably present on the relics of lateritic soils, and may therefore be better adapted to lower levels of plant nutrients than the other tree species.

(vi). The soils overlying and surrounding lead-zinc and copper deposits, in addition to being richer in the ore-metals, were also generally higher in phosphorus than the soils elsewhere in the region. The phosphorus at these localities may be derived from primary metallo-phosphate minerals present within the ore-deposits. The soils developed over the mineralised rocks were acid on the surface. Magnesium and manganese, the latter probably derived from the gossans which mask the ore-deposits in certain areas, were also high in some samples.

(vii). Although account must be taken of variations due to differences in the analytical methods used, comparison of the results of this investigation with those in other semi-arid regions of Australia suggests that the soils of the Dugald River Area are relatively low in nitrogen and molybdenum, but comparatively high in copper and manganese.

(8). <u>Background values for zinc, lead and copper in the soils</u>

The background value for an element in soil material is defined as, "the normal abundance of an element in barren earth material", (Hawkes and Webb, 1962). This figure, and likewise that for the upper limit of background variation, (the anomaly threshold), will vary from area to area, according to the maturity and type of soil and the parent material.

Typical metal contents for the soils of the Mt. Isa-Cloncurry region were obtained from a series of samples collected at half-mile intervals along the old Cloncurry-Mt. Isa road, (Fig. 1). The samples were collected at least 100 feet from the edge of the road to avoid any contamination from road materials, (Nicolls 1964).

Samples of bedrock and of the widespread grass, Triodia pungens, when available, were collected from each sampling point.

This traverse cuts across calc-silicates of the Corella Formation, equivalent in age and similar in lithology to those outcropping in the Dugald River Area. The variation in the zinc and lead results along the traverse is consistent with the presence of un-mineralised rocks, (Nicolls ibid), and these results were therefore made a basis for background and threshold determinations, (Table 5).

Table 5: Calculated Background and Threshold Results for Bisulphate-Extractable Zinc, Lead and Copper, (after Nicolls, 1964).

Metal	Range of Background Values-ppm	No. of Samples	Mean Background -ppm	Threshold-ppm (Mean Bkgd +2 Std. Deviation
Zn	15 - 50	41	25	50
Pb	5 - 25	42	5 - 25	5 - 25
Cu	5 - 40	92	15	60

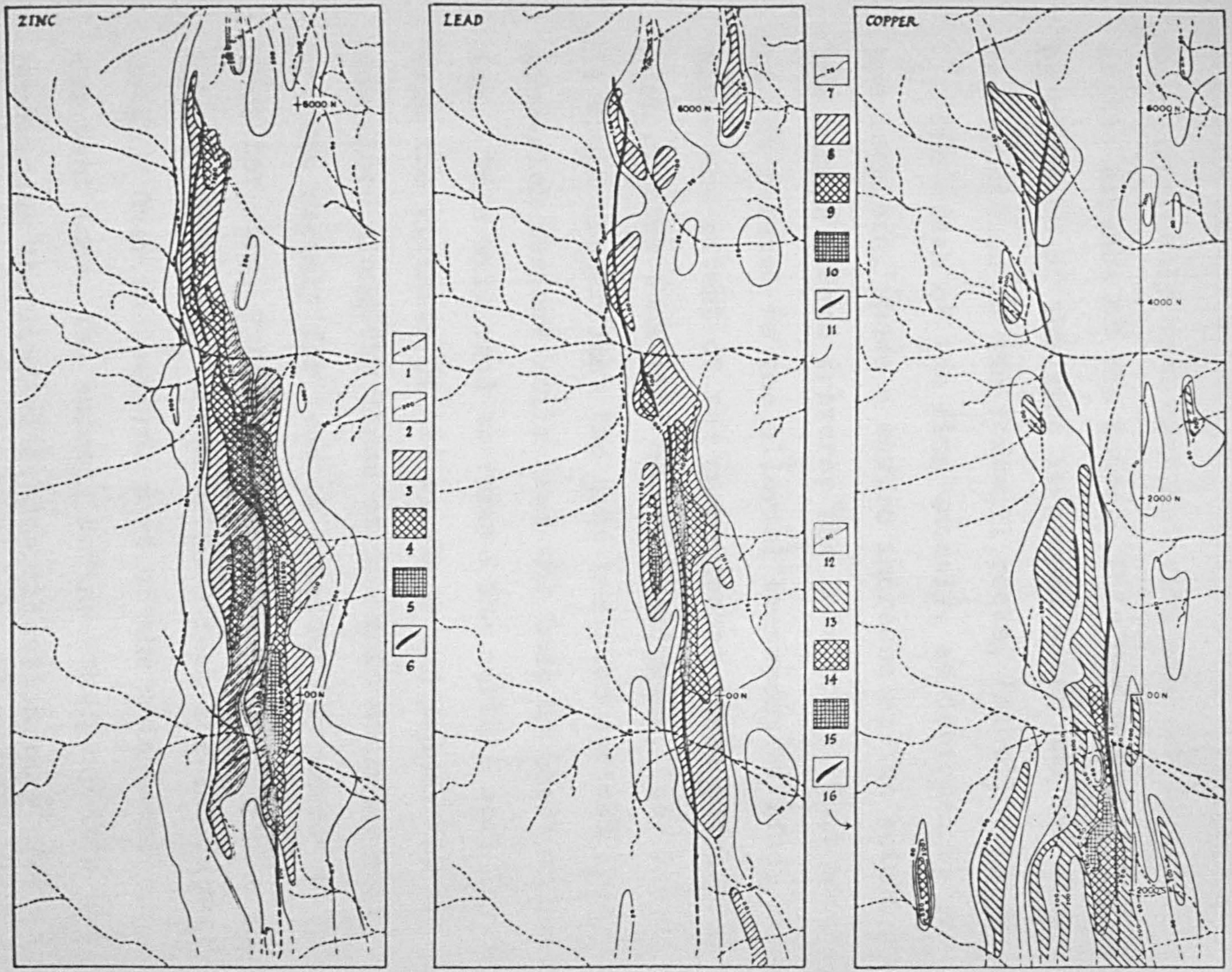
The results for copper, however, showed a more erratic distribution. In certain parts of the traverse the copper content in the soils did not exceed 10 to 15 ppm, but elsewhere values as high as 390 ppm were obtained, (Nicolls, ibid). This suggested that many of the samples were collected from within anomalies related to bedrock mineralisation, a suggestion consistent with the wide-spread nature of the copper mineralisation, most of it of subeconomic grade, within the Corella Formation. The background and threshold values for copper were therefore based on the results from 92 soil samples collected on the eastern slopes of the apparently un-mineralised Knapdale Quartzite, (Fig. 2). Using these results, the mean background value for copper is 15 ppm and the threshold value 60 ppm, (Table 5).

(9). <u>The distribution of zinc, lead and copper in the Lode Area soils</u>

The distribution of these metals in the surface layers, (4 to 8 inches), of the residual and transported soils of the Lode Area is shown in Fig. 5, (after Nicolls, 1964).

Perhaps the most striking feature of the maps is the pronounced north-south trend of the metal anomalies, thus conforming to the general strike of the country rock and reflecting the bedded nature of the ore-deposits.

The main zinc anomaly extends over the greater part of the Lode outcrop. Smaller anomalies are developed over the West Lode and are associated with the gossanous shales which appear to mark its continuation. A characteristic feature of the anomalies, however, is that the higher values occur, not over the ore-deposits as



Bisulphate extractable Zinc in the minus - 80 mesh fraction
(1) 50 P.P.M. (2) 200 P.P.M. (3) 800-3200 P.P.M. (4) 3200-12,800
(5) 12,800 and over (6) The Lead-Zinc Lode Shales

Bisulphate extractable Lead in the minus - 80 mesh fraction
(7) 25 P.P.M Isopleth (8) 100 - 400 (9) 400-1600 P.P.M.
(10) 1600 P.P.M. and over (11) The Lead-Zinc Lode Shales

Bisulphate extractable Copper in the minus - 80 mesh fraction
(12) 60 P.P.M. (13) 200-550 P.P.M. (14) 550-1600 P.P.M.
(15) 1600 P.P.M and over (16) The Lead-Zinc Lode Shales

SAMPLING DEPTH 4 TO 8 INCHES

FIG. 5

might be expected, but on their footwalls. The latter have apparently been enriched with zinc at the surface at the expense of the Lodes. This has probably occurred by solution of the zinc in ground water and its subsequent re-deposition in the footwall rocks, (Nicolls, ibid).

The width of the zinc anomaly, as depicted by the 50 ppm isopleth, shows a marked increase at the points where the larger creeks traverse the Lode zone. This increase is not related to the alluvial transport of zinc, however, since the extent of the anomalies at these localities is much greater than that of creek alluvium, (see Fig. 4B). It would appear that the zinc has been derived from the zinc-rich surface soils near the Lode by sheet wash erosion. This will tend to remove the surface soil layers from the vicinity of the ore-body and deposit it further downslope along the lines of the main drainage ways.

The anomaly for lead is considerably narrower than that for zinc, varying between 200 and 1300 feet, as against an average width of 2000 feet for the latter metal. Over the central part of the main Lode, and on the West Lode, the anomaly defines the graphitic shales containing the lead-zinc mineralisation very precisely, but towards the north and south the anomaly tends to be offset eastwards. These low-order anomalies are possibly related to weak mineralisation within the shale and limestone horizons at these localities. A similar explanation may account for the isolated lead anomalies on the argillaceous limestones in the north-east corner of the area. It is noticeable, however, that the distribution of the anomalies is restricted to the shale and limestone bands : the surrounding calc-silicates contain very little lead.

An interesting feature of the main lead anomalies is that, unlike zinc, the zones of maximum metal enrichment occur in the soils over the Lode, and not on the footwall. At the same time, however, the anomalies are much wider on the footwall side of the Lode than on the hangingwall. This may be related to the fact that the footwall shales form a relatively narrow horizon, which grades rapidly into argillaceous limestones. The soils developed on the shales are acid, (Table 4), while,generally speaking, the soils derived from the latter rock type have a basic reaction. The relatively high pH of the limestone soils may cause precipitation of lead in solution in water draining from the Lode ridge, and its concentration at the boundary between the shale and limestone horizons.

The copper anomalies in the soils of the Lode Area show the same north-south trend as those for lead and zinc. Apart from the example discussed below, however, the distribution of this metal shows no marked association with the lead and zinc anomalies. This agrees with the fact that the lead-zinc lodes contain very little copper.

Malachite staining is associated with the graphitic shales which contain the Lode at the northern end of its outcrop, however, and here gives rise to an extensive copper anomaly in the overlying soils. Apart from this example, the soils overlying the graphitic Lode shales are generally relatively poor in copper. On the other hand, the surrounding micaceous and siliceous shales and mudstones contain considerable amounts of this metal, particularly in the south where the hangingwall shales are stained with malachite. Soil copper contents in excess of 1600 ppm are associated with this latter occurrence.

Copper is also present in the soils overlying the gossanous shales west of the West Lode, though in part this anomaly is associated with the copper showings which occur at the contact between the shale and calc-silicates to the west, (Fig. 3A). Considerable quantities are also present in the soils overlying the limestone and shale horizons between the Main and West Lodes, with the soil copper content exceeding 2000 ppm in this narrow zone.

Extensive copper anomalies are associated with the copper showings which occur along the contact between the western band of calc-silicates and the shale horizon, (Figs. 3A and 5). These are generally of a low order, though soil copper contents in excess of 550 ppm are present over the largest of these occurrences, Patti's showing, in the south-west of the area. The soils overlying the eastern band of calc-silicates also contain some copper, but the resultant anomalies are of a low order.

Alluvium deposited along the banks of the larger creeks which drain the barren Quartzite Range has affected the continuity of the copper anomaly west of the Lode, as at 3600N and 4500N, (Fig. 5). Similar breaks are apparent in the lead anomaly at these localities, and probably have been formed in the same fashion.

Discussion

Comparison of the maps of the metal anomalies with that of the various types of soil and overburden which occur in the Lode Area, (Fig. 4B), indicates that the higher metal values are largely restricted to the areas occupied by residual soils. The colluvium derived from quartzite, sheet wash alluvium, and the alluvial material deposited along the creeks are generally low in the ore-metals. As mentioned above, the last type of deposit causes the discontinuities which appear in some of the lead and copper anomalies. The main zinc anomaly developed over the Lode zone and bordering shales shows no comparable breaks, however. This may be related to the fact that, within the soil or overburden, zinc appears to have a greater mobility than lead or copper, (Nicolls, 1964). Thus, transport of zinc from the soils overlying the Lode zone will take place at a faster rate than either lead or copper, thereby giving rise to the relatively high zinc contents in the recent material deposited along the creeks.

It is also interesting to note that, generally speaking, the soils rich in calcrete and other calcareous material, (the Grey Calcareous Soils), are low in the ore-metals. These soils are frequently developed from the softer varieties of calc-silicates, which are very low in lead and relatively poor in zinc. Copper mineralisation, however, is widespread in the calc-silicate horizons within the region, and one might therefore have expected that copper would have appeared in some of the sectors occupied by the Grey Calcareous Soils. Its absence may be related to the fact that the more siliceous varieties of calc-silicates form a more favourable host rock for copper mineralisation, a suggestion borne out by field observation. Alternatively, if copper deposits do occur in the softer type of calc-silicate, the high pH of the overlying soils may inhibit the secondary dispersion of copper and therefore its appearance in the near-surface soils.

Comparing the anomaly maps with those of the vegetation of the Lode Area, (Figs. 3B and C), suggests that high concentrations of ore-metal in the soil have a marked effect on the distribution of the tree, shrub and herbaceous species. The regions of maximum soil metal enrichment, such as over the central and southern parts of the Main Lode and on the West Lode, are entirely devoid of trees or shrubs, (Frontispiece). A marked change takes place in the ground vegetation also, with the more widespread species giving way to distinctive plant assemblages over the metal-rich soils. These variations, however, will be more fully discussed in Section C.

SECTION B: THE MAJOR VEGETATION UNITS OF THE DUGALD RIVER AREA

(1). Introduction

As discussed in the Introduction to this thesis, previous investigations of vegetation distribution in western Queensland have been made over a much wider area than in the present study. Due to variations within the vegetation units, therefore, a classification proposed for a large region may not give a meaningful picture of the vegetation distribution within a smaller area. For this reason, separate classificatory units have been set up for the Dugald River Area. These are indicated in Table 6, together with their deduced equivalents in other investigations.

Mapping of the major vegetation units was aimed at establishing the relationship between their distribution and the environmental factors. The latter comprise the bedrock geology, relief, soil and the geomorphological processes acting on the landscape. Recognition of the major vegetation units, and the relative importance of the various factors governing their distribution, thus formed a background for the study of the composition and distribution of the plant assemblages occurring over the mineralised zones within the region.

The following description of the vegetation is based on mapping at a scale of one inch to 2000 ft. over an

Table 6 : **Comparison of the Vegetation Units in the Dugald River Area with those of other Investigations.**

<table>
<tr><th>Sub-Formation (Cole, 1963)</th><th>Sub-Form (Williams, 1955)</th><th>Western Queensland (Blake, 1937)</th><th>Barkly Region. (Christian et al, 1954)</th><th>Dugald River Area Present study</th></tr>
<tr><td rowspan="5">Low Tree and Shrub Savanna</td><td rowspan="5">Low Arid Woodland</td><td rowspan="5">Eucalyptus brevifolia (ex pallidifolia) - E. leucophylla - Triodia community</td><td rowspan="3">Eucalyptus brevifolia association (Woodland)</td><td>E. brevifolia - Triodia pungens association</td></tr>
<tr><td>E. brevifolia - E. dichromophloia - Triodia pungens association</td></tr>
<tr><td>E. brevifolia - Acacia chisholmi - Cleome viscosa association</td></tr>
<tr><td rowspan="2">Eucalyptus argillacea - E. terminalis sub-alliance (Shrub Woodland)</td><td>E. argillacea - E. terminalis - Acacia chisholmi - Triodia pungens association</td></tr>
<tr><td>E. argillacea - E. terminalis - Carissa lanceolata - Sporobolus australasicus</td></tr>
<tr><td>Thicket and Scrub</td><td>Low Layered Woodland</td><td>Acacia cambagei scrub</td><td>Acacia cambagei association, (Shrub Woodland)</td><td>Acacia cambagei association</td></tr>
<tr><td>Savanna grassland</td><td>Tussock grassland</td><td>Astrebla grassland</td><td>Astrebla pecti nata association (Grassland)</td><td>Astrebla pectinata - Iseilema macrathera association</td></tr>
<tr><td></td><td></td><td>Fringing Forest</td><td>Tall Fringing Forest</td><td>Melaleuca leucadendron - E. camaldulensis - Tristania grandiflora community</td></tr>
</table>

area measuring approximately 5 by 12 miles, (Fig. 6). Mapping was carried out using aerial photograph enlargements, the dominants of each stratum and boundaries between the vegetation units being plotted directly in the field.

Larger scale maps were prepared of the Lode and Turkey Creek Areas, containing lead-zinc and copper mineralisation respectively, and of the area designated, "The Area north-east of the Quartzite Range", (Fig. 2). At these localities the dominants of the tree/shrub strata and those of the ground vegetation have been depicted on separate maps. Variations in the vegetative cover within these areas have also been illustrated by transects.

Although for the purpose of description the various associations have been generally treated as discrete units, it should be emphasised that many gradations occur in the field. Attempt has been made to indicate these on the larger scale maps, but this was not possible on the scale used for the regional map.

Gradational zones are especially common between the various associations included in the sub-formation of Low Tree and Shrub Savannah. Here there is much overlapping between the units, with one species sometimes occurring as a dominant in two or three associations though the other dominants vary. Thus the sub-formation may be thought of as a continuum, altering by stages in its specific make-

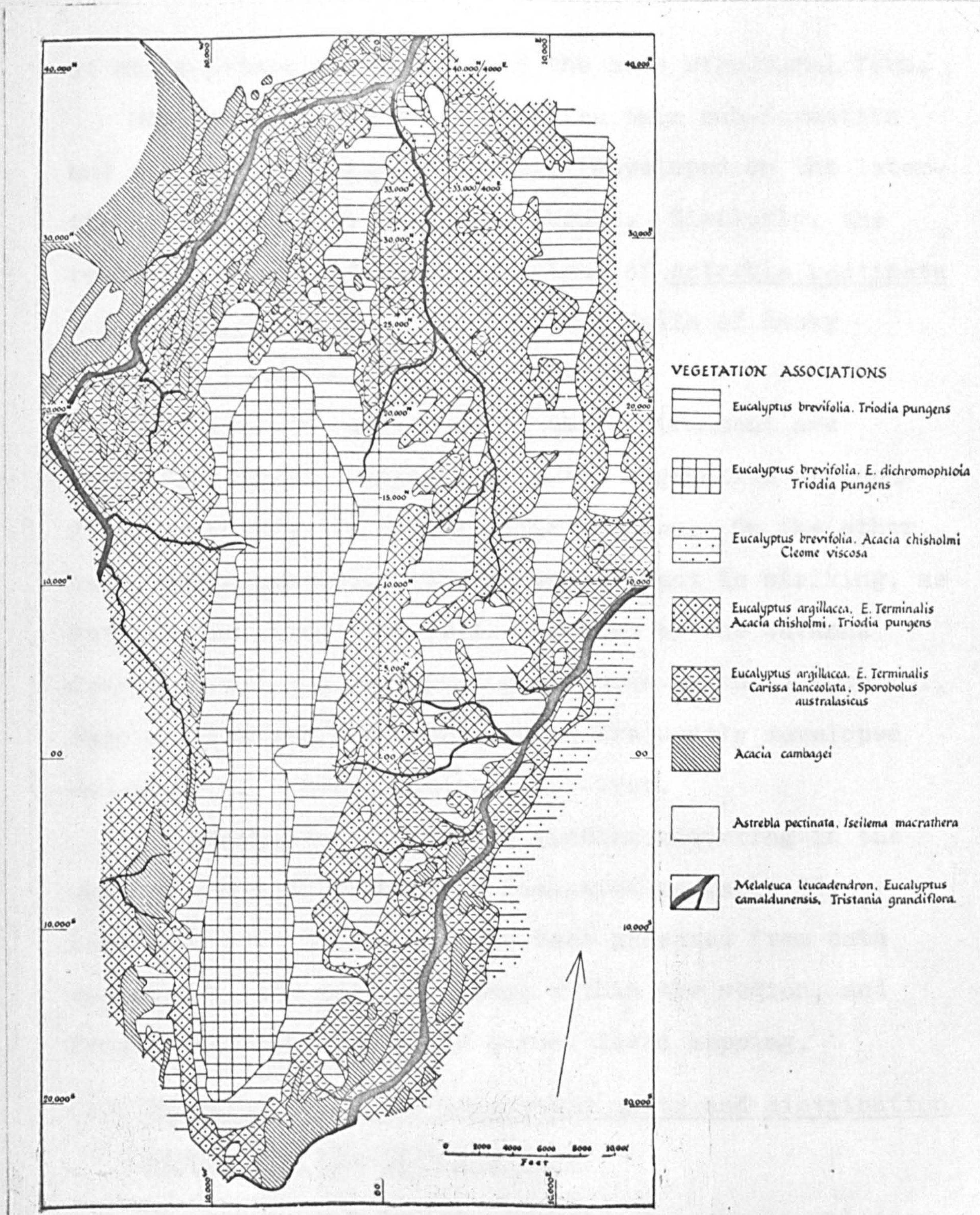


Fig. 6 Vegetation Map of Dugald River Area

up while retaining essentially the same structural form.

However, the boundaries between this sub-formation and the Acacia cambagei Thicket, (developed on the laterite residuals), are generally abrupt. Similarly, the boundary with the Savanna Grassland of Astrebla pectinata - Iseilema macrathera, (on the Grey Soils of Heavy Texture), is normally fairly distinct.

Hence, where variations in the environment are relatively small, variations in the vegetation are confined to changes in the specific make-up. On the other hand, where the change in the environment is striking, as between the heavy clay soils occupied by the Savanna Grassland and the surrounding, lighter-textured material, then a different sub-formation is frequently developed and there is little species carry-over.

A comparative list of the species occurring in the various vegetation units is indicated in Table 35, (Appendix C). This table has been prepared from data recorded by the transects made within the region, and from notes made during the actual field mapping.

(2). Description of the vegetation units and distribution within the Dugald River Area

(a). Eucalyptus brevifolia - Triodia pungens association

E. brevifolia F. Muell. is a low, (5-8 m.), tree with two or three main branches springing from a short trunk.

It bears a sparse crown of small, glaucous, greyish-green leaves, while the bark is smooth and white to pinkish in colour, (Plates 8,9). Other trees occurring in the association include E. papuana, E. terminalis, Terminalia aridicola Domin., and, rarely, E. aspera F. Muell. E. pruinosa Schauer is also quite frequent in the north-west of the area.

The shrub layer is generally sparse or absent, though on lower ground Carissa lanceolata R.Br. is generally present along sandy drainage channels and creeks. Acacia coriacea D.C. occurs in rocky regions, while Acacia retivenia F. Muell. and Maytenus cunninghamii (F. Muell.) Loes, may be found in similar country or on lower areas of quartzite rubble.

The tree spacing is relatively open, the intervening areas being dominated by the viscid, spiny grass, Triodia pungens. This species forms low hummocks, up to several feet in diameter and 18 ins. high. In many cases the centre of the hummock dies off while the plant continues growth outwards.

Spaces between the hummocks are occupied by a sparse growth of Cleome viscosa, which replaces T. pungens as dominant where areas have been apparently burned off. Sporobolus australasicus is common, particularly on fine-textured soil. In these areas, the following herbs and grasses are also frequent; Tribulus pentandrus Benth.,

Plate 8 *Eucalyptus brevifolia* - *Triodia pungens* Association on shales

Plate 9 *Eucalyptus brevifolia* - *Triodia pungens* Association on quartzite rubble and gravel

Plate 8 Eucalyptus brevifolia - Triodia pungens Association on shales

Plate 9 Eucalyptus brevifolia- Triodia pungens Association on quartzite rubble and gravel

Gomphrena brownii, Ptilotus fusiformis var. gracilis Poir., Portulaca intraterranea J.M. Black, Heliotropium tenuifolium R.Br., Eulalia fulva Kuntz., Eriachne pulchella Domin., and Enneapogon polyphyllus (Domin.) Burbridge.

Where developed on the higher ranges, the following species also occur; Polycarpaea corymbosa Lam., Boerhavia diffusa L., Amaranthus interruptus R.Br., Indigofera linifolia Retz., Enneapogon oblongus N.T. Burbridge, Schizachyrium sp., Eriachne mucronata R.Br. and Paspalidium rarum D.K. Hughes.

This association is generally restricted to more acid environments, (pH 5.9-6.2, Table 4). It forms a more or less continuous zone on the quartzite rubble and gravel bordering the Quartzite Range, (Fig. 6). On the Range itself, however, it is replaced by another association, described below. It is also developed on stretches of coarse alluvium on the plains, on the high range of siliceous rocks near the eastern margin of the area, and on the lower hills and ridges formed of shales and siliceous calc-silicates.

(b). Eucalyptus brevifolia - E. dichromophloia - Triodia pungens association

This association bears many similarities to the previous one, but differs in the occurrence of E. dichromophloia F. Muell. as a co-dominant. This species grows to 6 - 8 m. in height, and, unlike E. brevifolia, has a rather slender single trunk, covered by pink, slightly ridged bark.

The trees grow widely spaced, and, in addition to the dominants, E. terminalis and Terminalia aridicola are quite common in places. Acacia phlebocarpa F. Muell. is virtually the sole member of the shrub layer, and forms fairly dense cover in places. The ground storey is dominated by Triodia pungens, while Cleome viscosa and Enneapogon oblongus are frequent sub-dominants. Other herbs and grasses include: Borreria australiana, Ptilotus fusiformis var. gracilis, Solanum ellipticum R.Br., Heliotropium tenuifolium, Gomphrena brownii, Schizachyrium sp., and Eriachne pulchella.

As in the case of E. brevifolia - Triodia pungens, this association is characteristic of an acid environment, (pH 5.8-6.0). Its distribution, however, is restricted to the high rocky uplands of the Quartzite Range. Run-off from this area must be very rapid, but presumably the vegetation survives by tapping water held in crevices within the rock.

(c). Eucalyptus brevifolia - Acacia chisholmi - Cleome viscosa association

E. brevifolia occurs as a widely spaced low spreading tree as in the previous associations, but in this unit the turpentine bush, Acacia chisholmi, forms a fairly dense cover. This species grows to 6 ft. or more, with several main branches covered by brown scaly bark, and a spreading crown of viscid, bright green leaves.

Other trees include Terminalia aridicola, Eucalyptus terminalis and, on a ridge overlooking the Dugald River, a small stand of the bottle tree, Brachychiton australe Terr., (Plate 2).

Cleome viscosa, a tall viscid herb, forms a rather sparse ground cover, with Triodia pungens, Enneapogon oblongus, Eriachne mucronata R.Br., Heliotropium tenuifolium and Boerhavia diffusa also important.

This association is generally restricted to a hilly range of calc-silicates bordering the east bank of the Dugald River, (Fig. 6). There is a slight improvement in soil development over that on the Quartzite Range, and presumably this, possibly with the more calcareous conditions, allows the growth of Acacia chisholmi. Apart from the occurrence of this shrub, the association bears a close resemblance to the previous ones.

(d). Eucalyptus argillacea - E. terminalis - Acacia chisholmi - Triodia pungens association

This is the most widespread association of the region, (Fig. 6). Eucalyptus argillacea forms an open woodland of low, (5 - 7 m.), spreading trees, with several main branches, covered by a light greyish/brown fibrous, ridged bark, carrying a sparse crown of light green lanceolate leaves. *E. terminalis* (bloodwood), differs in habit, with a single erect trunk reaching 10 m. in height, bearing a fairly dense crown; the bark is mottled brown to orange in colour and is covered by small scales which, near the base, exudes a red gum, (Plate 10).

The two species normally occur as co-dominants, although each may form the sole constituent in places. Other tree species occurring include the tall *E. papuana*, *Grevillea mimosoides* R.Br., *Acacia hemignosta* F. Muell., *Hakea suberea* S. Moore, *Maytenus cunninghamii*, *Atalaya hemiglauca* F. Muell. and *Acacia bidwilli* Benth.

Acacia chisholmi forms a shrub cover of variable density. In certain regions, this species is absent entirely, while in others, particularly along drainage lines and on the more calcareous areas, it forms a dense, sometimes impenetrable, growth. Other shrubs are rare, though *Myoporum montanum* R.Br. sometimes occurs in the more open areas, while *Acacia lysiphloia* F. Muell. and *Cassia desolata* may be found with *A. chisholmi*.

The ground vegetation is dominated by a fairly dense cover of *Triodia pungens*, though *Cleome viscosa* is also important in most regions and sometimes forms the dominant species. The spaces between the *Triodia* hummocks are occupied by numerous herbs and grasses, including the following; *Ptilotus fusiformis* var. *gracilis*, *Boerhavia diffusa*, *Tribulus terrestris* and *Heliotropium* spp.,

Plate IO Eucalyptus argillacea - E. terminalis - Acacia chisholmi - Triodia pungens Association on calc-silicates

Plate II Eucalyptus papuana on interfluvial tract occupied by Arid Red Earths

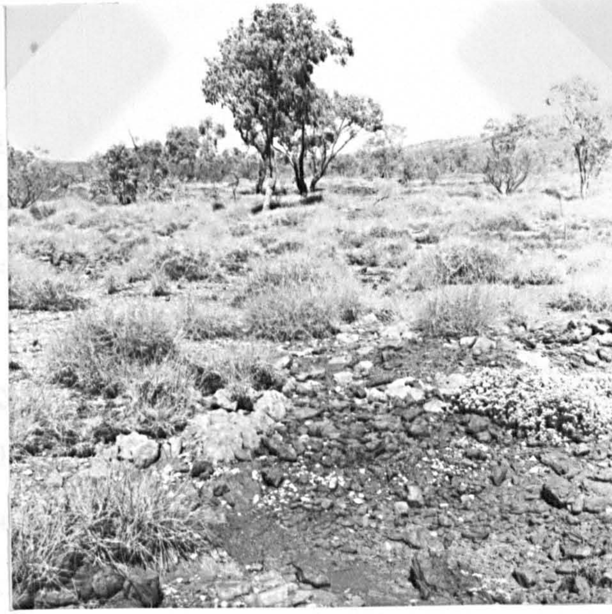


Plate IO Eucalyptus argillacea - E. terminalis - Acacia chisholmi - Triodia pungens Association on calc-silicates

Plate II Eucalyptus papuana on interfluvial tract occupied by Arid Red Earths

Scaevola densivestita Domin., Gomphrena brownii, Ptilotus clementii var. pearsonii, Andrachne decaisnei Benth., Enneapogon polyphyllus, E. oblongus, Sporobolus australasicus, Eulalia fulva, Eriachne pulchella and, in certain localities, Triodia longiceps J.M. Black.

This association is generally restricted to areas of more or less calcareous soils, (P. 70). Thus it is normally present in areas underlain by calc-silicates, (with the exception of the more siliceous varieties), and limestones. Since these rocks are more susceptible to erosion than the harder siliceous types, they form relatively low, undulating country. The soils are normally skeletal. With increase in the depth of soil cover, the association generally gives way to the one described below.

(e). Eucalyptus argillacea - E. terminalis - Carissa lanceolata - Sporobolus australasicus association

E. argillacea and E. terminalis form the dominant trees in this association, though in places one or other may be absent, and, in certain localities, may be replaced by E. papuana. With Atalaya hemiglauca, the last species is particularly common on areas of flat, poorly drained ground, (Plate 11).

In the north-west, E. pruinosa may form an important member of the tree storey. Acacia cambagei occurs as separate stands within the association, while Bauhinia carronii F. Muell., (generally along drainage lines), and Hakea suberea S. Moore may also be present.

Carissa lanceolata, a spiny shrub, 4 to 6 ft. in height, with light green lanceolate leaves, forms a sparse shrub layer. On some of the better drained soils its place is taken by Acacia chisholmi which here forms quite thick cover. Cassia desolata F. Muell., Eremophila latrobei F. Muell., Maytenus cunninghamii and Myoporum montanum are also quite frequent.

The ground storey is normally sparse. Sporobolus australasicus occurs as a short annual grass, normally growing to a height of several inches. Triodia pungens is also common in the better-drained localities, forming a series of widely spaced hummocks. Where the centre has died off, this forms a favourable situation for a number of other species, including Solanum ellipticum and Pterocaulon verbascifolium F. Muell.

Other short annual grasses occurring with S. australasicus include; Aristida browniana, Enneapogon polyphyllus, Tragus australianus S.T. Blake, Perotis rara. The following occur less frequently; Chrysopogon fallax S.T. Blake, Aristida pruinosa Domin., Brachyachne convergens Stapf., Dactyloctenium radulans Beauv., Paspalidium rarum, Eulalia fulva and Eriachne pulchella. Iseilema macrathera, Eragrostis japonica Trin. and Chloris acicularis Lindl. may be found in clayey depressions.

The tall herb Cleome viscosa is generally common throughout the area occupied by this association, though tends to avoid the poorer-drained localities. It forms a sparse cover with a number of other, generally small, annual herbs, including; Comphrena brownii, Tribulus pentandrus, T. terrestris, Portulaca intraterranea, Breweria media and Ptilotus fusiformis var. gracilis. Scaevola densivestita and Heliotropium tenuifolium are also common on more calcareous soils.

This association is developed on areas occupied by the Arid Red Earth soils, of sandy clay loam to clay texture. Similar material occurs on the flood plains of the major rivers where, in addition to the present association, large tracts of the Acacia cambagei association are also present, (Fig. 6).

During the dry season, the areas occupied by this association generally present a very bare appearance, (Plate 11), with most of the herbaceous stratum having died off. Immediately after the first rains, which tend to cause flooding due to the low gradients and high clay content in the soil, there is a sudden growth of short annual grasses and herbs.

(f). Acacia cambagei association

The dominant of this association is a low erect tree whose timber is frequently used for fencing, etc..

Several branches bearing a rather dense crown of greyish green leaves spring from a short trunk covered by rough grey bark, (Plates 12, 13). The flowers are yellow and, like the leaves, emit a foetid odour after rain.

The tree occurs in two distinct environments. On the one hand, it forms a low dense woodland on lateritised shales, limestone and Mesozoic sediments in the west and north of the area. Apart from a few occurrences of _E. brevifolia_ and _Eremophila mitchelli_, other trees are rare. An open shrub layer is present, however, with _Cassia desolata_ and _Eremophila latrobei_ fairly frequent, and _A. chisholmi_ less so. The ground vegetation is sparse or absent entirely, presumably due to the high iron content of the soil and the heavy shade. However, the grasses _Paspalidium rarum_, _Eulalia fulva_, _Schizachyrium_ sp., _Eriachne mucronata_ and _Triodia pungens_ may be locally important.

Similar, though more open, stands occur extensively on the flood plains of the major rivers, (Fig. 6), and, less frequently, on gravelly areas on the level interfluves and plains occupied by Arid Red Earths, (Plate 13). An identical shrub storey is present, while _Sporobolus australasicus_ forms a low, sparse herbage.

On the flood plain occurrences, this association grades into a more open woodland with _Eucalyptus terminalis_, _E. argillacea_, _Atalaya hemiglauca_ and _E._

Plate I2 Acacia cambagei on summit of Mesozoic Mesa

Plate I3 Acacia cambagei on flood plain of the Dugald River

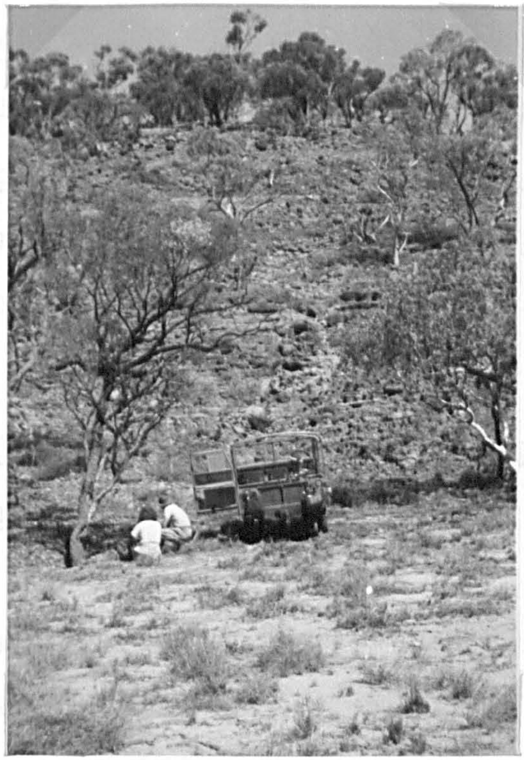


Plate I2 Acacia cambagei on summit of Mesozoic Mesa

Plate I3 Acacia cambagei on flood plain of the Dugald River _pruinosa_. _Carissa lanceolata_ comes in as an important member of the shrub stratum in addition to those named above. _Sporobolus australasicus_ with _Aristida browniana_ and occasionally _Brachyachne convergens_ form a sparse herbaceous stratum, while scattered tussocks of _Triodia pungens_ are also frequent.

(g). _Astrebla pectinata - Iseilema macrathera association_

A. pectinata is a perennial tussock grass, growing to a height of 30 ins., with the tussocks varying between 18 and 36 ins. apart. _I. macrathera_ has a profusely-branched habit, with reddish-tinged culms and sheaths; it is a rather tall (12 - 18 ins.) annual which, however, persists well into the dry season.

The association is confined to the Grey Soils of Heavy Texture on the flood plain of Cabbage Tree Creek, (Plate 14). The surface consists of a series of low hummocks and depressions which, during the dry season, are traversed by a series of deep cracks. The dominant grasses are generally restricted to the hummocks, with the intervening spaces occupied by a thick herbage which includes the following species; _Ocimum sanctum_, _Hibiscus trionum_ L., _H. ficulneus_, _Ipomoea lonchophylla_, _Neptunia gracilis_, _Euphorbia uhligiana_, _Ptilotus spicatus_ F. Muell. var. _leianthus_.

Trees and shrubs are virtually absent, though small clumps of _Acacia cambagei_ occur in places.

Plate I4 Astrebla pectinata - Iseilema macrathera Association on Grey Soils of Heavy Texture

Plate I5 Melaleuca viridiflora and Eucalyptus camaldunensis along the Dugald River

Plate I4 Astrebla pectinata - Iseilema macrathera Association on Grey Soils of Heavy Texture

Plate I5 Melaleuca viridiflora and Eucalyptus camaldunensis along the Dugald River

Alternanthera denticulata R.Br., Malvastrum spicatum A. Gray, Melothria maderaspatana Cogn. and Crotalaria aff. novae hollandiae D.C. Prod. The beds of the smaller creeks support a fairly sparse herbage of Cleome viscosa, Boerhavia diffusa, Indigofera spp., Eriachne obtusa R.Br., Heteropogon contortus Beauv. ex Roem and Schult., Chrysopogon fallax, Triodia pungens, Cyperus iria L., Iseilema macrathera and numerous other species. Citrullus vulgaris Schrad. occurs occasionally on sandbanks in the beds of the major rivers and near the smaller creeks.

(3). The Lode Area

(a). Introduction

The major geological and physical features of the Lode Area have been previously described, (pp. 48, 49), and only a short outline will be given here. It lies near the eastern margin of the Knapdale Quartzite, (Fig. 2), which forms rugged country in the west of the area, (Figs. 3A and 4A). Parallel to the Quartzite Range, and separated from it by a wide zone of calc-silicates, runs the north-south ridge of shales and mudstones which contain both the Main and West lead-zinc Lodes, (Frontispiece). Northwards this unit lenses out between the calc-silicates in the west and a thick horizon of dark argillaceous limestone, while to the east the latter is bounded by thin bands of shale, calc-silicates and quartzite.

As evidenced by the geological map, (Fig. 3A), the strike of the country rock is roughly north-south, while the regional dip is steeply west.

The base of the Quartzite Range is flanked by a thick, gently-sloping, deposit of coarse colluvial material derived from the neighbouring higher ground, (Fig. 4B). At the southern end of the area this grades into finer-textured sheet wash alluvium on a level vale, but in the north this unit is absent due to the convergence of the Quartzite Range and the Lode Ridge. The shale and limestone horizons are largely covered by residual material, while on lower ground underlain by outcropping calc-silicates, calcrete and other calcareous material predominates.

The major creeks flow from west to east, although several of the larger tributaries have cut back north-south along the strike of the country rock. Wide terraces covered by coarse quartzitic alluvium border the creeks along the greater part of their length. Where the drainage has cut through the Lode Ridge, however, the terraces are absent or much constricted.

(b). <u>Tree and shrub cover</u>

The distribution of the major trees and shrubs is indicated in Fig. 3B. <u>Eucalyptus brevifolia</u>, joined in the higher regions of the north-west corner of the area by <u>E. dichromophloia</u>, forms a low open woodland on the slopes of the Quartzite Range and derived colluvium, and on the southern part of the outcrop of shales and mudstones, (Plate 8). Smaller stands are developed on low ridges of siliceous fragmental calc-silicates east of the shale outcrop. Comparison of the distribution of this species with the form line map, (Fig. 4A), indicates its close correlation with the regions of relatively high topography.

The species E. argillacea and E. terminalis are widespread, occurring on all rock types with the exception of the quartzite and quartzite boulder conglomerate. They are, however, generally restricted to lower ground; where they border on the E. brevifolia association on the high ground to the west, an intermediate gradational zone of all three species is generally present.

Acacia chisholmi forms a fairly dense shrub layer along the smaller creeks, particularly where erosion has exposed calcrete and other calcareous material, (Fig. 4B). Stretches of sheet wash alluvium on the lower ground in the south, central and eastern parts of the area generally carry an open woodland of E. argillacea and/or E. terminalis.

The main southern development of the Main Lode, (Fig. 3A), the West Lode and a smaller area on a creek terrace to the west, are generally treeless. In the former areas, this is presumably due to toxic conditions in the soil produced by the high concentrations of lead and zinc.

The main creeks of the area are bordered by a distinct community of Eucalyptus camaldunensis, Tristania grandiflora and Terminalia aridicola.

(c). Ground vegetation

Triodia pungens is the dominant member of the ground storey over the major part of the area, (Fig. 3C). In small parts in the south and north, it is replaced by Cleome viscosa. Since the conditions in these areas are outwardly similar to those in which T. pungens is well represented, it is probable that its absence here is due to fire. These are intentionally started by the local stock-men to bring on fresh growth at the beginning of the wet season.

The level stretches of sheet wash alluvium, (Fig. 4B), carry a sparse growth of Sporobolus australasicus. Aristida browniana is common in these areas, and also forms separate communities in the vicinity of the Lode at certain localities. The low woody herb Scaevola densivestita is generally restricted to outcropping calcrete and other calcareous material. Triodia longiceps, a harder, more spiny species than T. pungens, may occur in similar environments and is also present at the south end of the shale outcrop. The other species mapped are generally associated with mineralisation, and will be discussed in Section C.

(d). Discussion

Comparison of the vegetation maps of the Lode Area with those of the topography and overburden, (Figs. 3B, C and 4A, B), strongly suggest that the distribution of the more widespread plants are largely controlled by relief and edaphic factors.

This is further borne out by examination of the findings of Transect 4, (Fig. 7), which runs east-west across the area, (Fig. 4C). Three groupings of the plant species, each of them characteristic of a distinct environment in terms of the relief and soil, may be distinquished.

(i). On the well-drained upland areas underlain by quartzite and shales, where the soils are acid, (Table 4), and contain abundant gravel-sized fragments:- Eucalyptus brevifolia dominates the tree storey and Triodia pungens the herbaceous vegetation. Apart from Cleome viscosa, which is almost ubiquitous, Eulalia fulva and Tribulus pentandrus, the majority of the other herb and grass species are virtually absent.

(ii). On areas of intermediate elevation, underlain by calc-silicates and limestones, with residual soils containing calcrete nodules:- Eucalyptus argillacea and E. terminalis are the most abundant members of the tree stratum. Triodia pungens, while still common, is

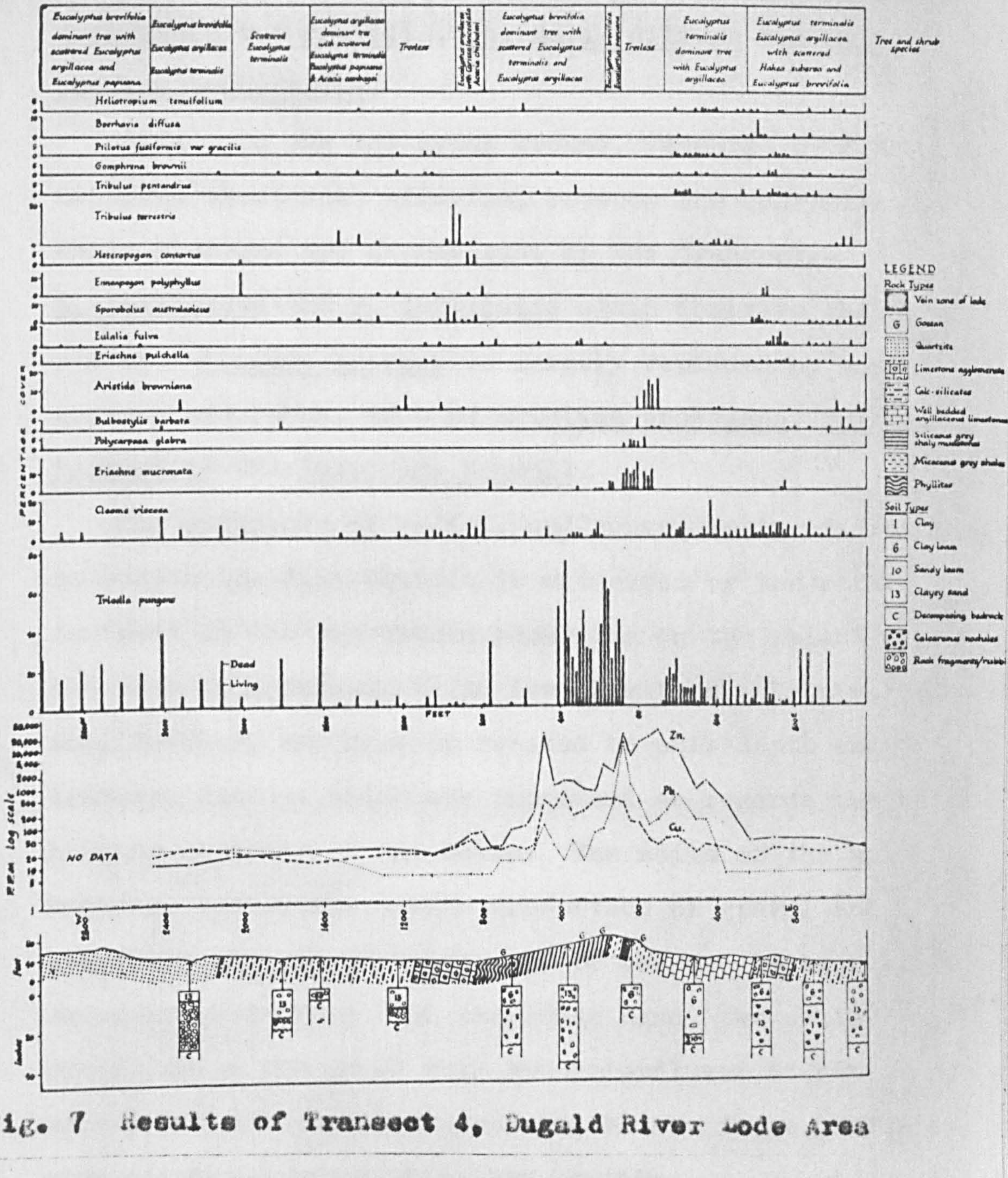


Fig. 7 Results of Transect 4, Dugald River Lode Area

now joined by numerous annual herbs and grasses, including Sporobolus australasicus, Tribulus pentandrus, Ptilotus fusiformis var gracilis, Boerhavia diffusa and Heliotropium tenuifolium.

(iii). On the low-lying ground, veneered by fine-textured sheet wash alluvium, between the quartzite and shale horizons and at the east of the transect:- E. argillacea and E. terminalis again dominate the tree storey. Triodia pungens is largely replaced by annual grasses and herbs, such as Aristida browniana, Tribulus terrestris and Gomphrena brownii.

The influence of relief, and consequently of drainage, on vegetation distribution is witnessed by the marked contrast in the vegetation occurring on the upland areas and that on intermediate to low elevation. This variation, however, may also be related to soil depth and texture, factors which are important as regards the water-holding capacity of the soils. The soils of the upland regions, containing a high proportion of gravel and generally shallow in depth, may be assumed to be well to excessively-drained. On the other hand, the soils occurring on the level vale and interfluves at low elevations are poorly-drained due to the large amount of clay-sized constituents in the profile.

In addition, there is a marked contrast in the vegetation occurring on the acid soils derived from shales and quartzite and that found on the basic soils developed on limestones and calc-silicates. It appears, therefore, that the pH of the soil, together with those factors which govern the soil-moisture status, largely controls the distribution of the more widespread vegetation units in the Lode Area.

A full discussion of the distribution of the vegetation over the Lode will be delayed until the following section. At this stage, however, attention may be drawn to the striking change in the herbaceous cover over the mineralised zone, and the associated absence of trees. The dominant members of the ground vegetation, Triodia pungens and Cleome viscosa, are here replaced by an assemblage of Eriachne mucronata, Polycarpaea glabra, Bulbostylis barbata and, in this sector of the Lode, Aristida browniana.

(4). The Area north-east of the Quartzite Range

(a). Introduction

The location of this area is indicated in Fig. 2. It is of interest because of the occurrence here of Tephrosia sp. nov. (Dugald R. MMC/DMJP No. 5), and Bulbostylis barbata, species associated with mineralisation in other parts of the region. In addition, the area offered scope for study of the relationships between the distribution of major vegetation units and variations in the soils and overburden.

The general drainage direction is from south to north. The major creek lies in the eastern part of the region, while a series of small creeks and wash areas drain the remainder, (Fig. 8B).

Most of the southern part is occupied by gently inclined sheets of rubble and gravel, derived by erosion from the Quartzite Range which lies some distance to the south-west. Similar material covers a broad zone bordering the creek in the east and isolated areas on the plain in the north. The latter, however, is generally veneered by fine-textured Arid Red Earth soils.

As discussed in the preceding section, it appears that these deposits have been largely derived by sheet wash erosion from the Quartzite Range. At the present time, however, stream erosion is also important. Where the smaller creeks traverse the quartzite rubble, they are deeply dissected with banks several feet in height. On debouchment to the plain, they merge into shallow wash areas floored by the fine sand and loam, which they have deposited. An exception is the linear drainage line running north-west from near the centre of the area. This forms a marked feature on aerial photographs and, from its linearity and length, (nearly two miles), it seems probable that it is man-made.

The geology is poorly exposed, but, from the few scattered outcrops it is apparent that the area is entirely underlain by calc-silicates. In the west these are a reddish variety with breccia-like appearance. Eastwards, they give way to a different type interbedded with bands of hard, dark grey siltstone.

(b). Tree and shrub cover

The distribution of the major trees and shrubs is indicated on Fig. 8A. *Eucalyptus brevifolia* dominates a low open woodland over the southern and western parts of the area, where it occurs on quartzite rubble and gravel As this grades northwards to finer material, *E. brevifol* goes out, to be replaced by a bordering zone of *E. argillacea* - *E. terminalis* with scattered patches of the shrub *Carissa lanceolata*.

Much of the remaining area carries only a few scattered trees of the species *E. argillacea*, *E. terminalis*, *E. papuana*, and *Atalaya hemiglauca*, though *C. lanceolata* is quite common. *Acacia cambagei* forms a fairly dense low woodland on stretches of gravelly material. Other areas, apparently those with better soil-moisture status, are occupied by a shrub woodland of *E. argillacea* - *E. terminalis* and the tall shrub *Acacia chisholmi*. In places, this last species forms dense thickets, while, in the more gravelly regions, it is restricted to scattered clumps and is generally in poor condition. *Cassia desolata* is an important sub-dominant. Isolated patches of rubble carry *E. brevifoli*

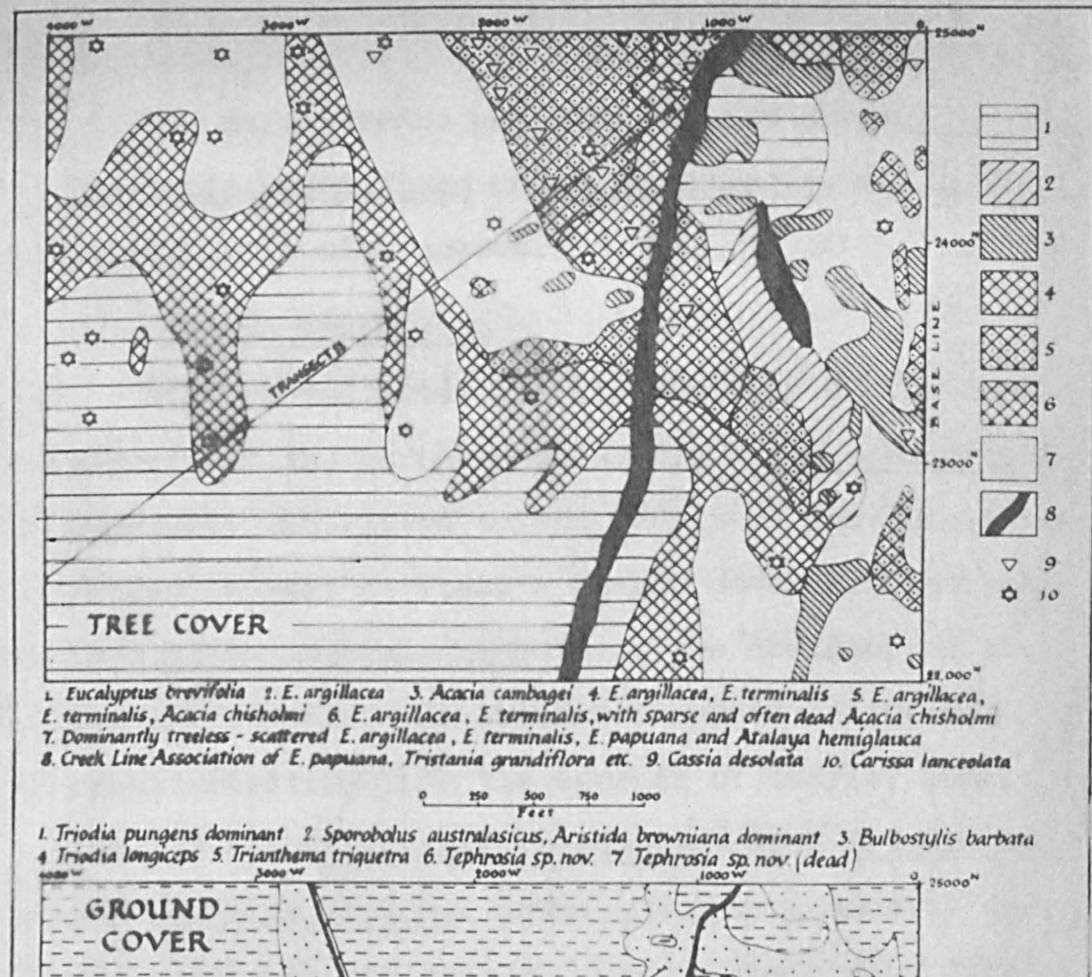


Fig. 8.A,B. Distribution of (A) the Dominant Trees and Shrubs, and (B) the Ground Vegetation, in the Area north-east of the Quartzite Range.

woodland.

The major creeks are lined by the trees _E. papuana_, _Tristania grandiflora_ and _E. argillacea_, while _Acacia chisholmi_ is also common.

(c). Ground vegetation

Fig. 8B indicates the distribution of the dominant members of the herbaceous layer. _Triodia pungens_ is generally restricted to the rubbly or gravelly material, though in the east it forms a sparse cover on finer material. _Sporobolus australasicus_ forms the dominant on the Arid Red Earth soils, and is also frequent on the sandy wash areas extending into the spreads of coarser material. The low herb _Trianthema triquetra_, with _Triodia longiceps_ and _S. australasicus_, forms a sparse community on quartzite rubble in the eastern part of the area. Current erosion has removed the top soil at this locality, and this has apparently inhibited the growth of other species.

The distribution of the shrub, _Tephrosia_ sp. nov., generally represented by dead stalks and branches, has been indicated on the map, (Fig. 8B). In common with the low sedge, _Bulbostylis barbata_, this species has a scattered distribution over the quartzite rubble in the western part of the area.

(d). Discussion

This region differs from the Lode Area in the lack of any marked variation in the relief, and hence this facto plays a relatively minor role in vegetation distribution As in the latter area, however, the drainage factor appears to have a powerful influence on the aerial exten of the vegetation units.

A feature of the area is the virtually complete absence of tree cover over a large part of the level plain which occupies the northern and eastern sectors. This is probably related to the low gradients and to the high clay content of the Arid Red Earths occurring in th region. As evidenced by their water-logged condition after rains, the drainage at these sites is very poor. The compact nature of the soils indicates a low porosity and it is probable that the bulk of the rain water recei during the wet season is evaporated before it reaches an great depth in the profile.

On the other hand, the high porosity of the coarse quartzite debris in the southern and western parts of this area ensures that a higher proportion of the rain water reaches the deeper soil horizons. Hence evaporati will take place at a slower rate during the ensuing dry season.

These variations in the rate of water-loss from the soils probably explains the preference for sites under-lain by coarse-textured material shown by the tree speci and by the perennial grass <u>Triodia pungens</u>. On the othe hand, the concentration of the tree and shrub species along the large creek in the eastern part of the area is probably associated with a localised rise in the water table.

Transect II, which runs from north-east to south-west across the western half of the area, provides a quantitative estimation of these variations in the vegetative cover. The results, (Fig. 9), show the marked contrast between the species found on the quartzite rubble and those on the Arid Red Earth soils which occupy the eastern half of the transect. The characteristic species of each site are enumerated below.

(i). On the gently-sloping deposits of coarse quartzite debris:- Eucalyptus brevifolia dominates the tree storey, with E. terminalis occurring sparingly towards the level plain in the east, and E. dichromophloia on the outcropping quartzite in the west. The ground storey comprises Triodia pungens and Cleome viscosa, with Bulbostylis barbata, Eulalia fulva and Heliotropium tenuifolium having a sparser distribution. Ptilotus fusiformis var. gracilis is found on the area underlain by outcropping quartzite.

(ii). On the Arid Red Earth soils:- two further subdivisions may be made in this sector. Within the zone 800 to 1600W E. argillacea, E. terminalis and E. papuana form a very open tree cover, while the shrub Carissa

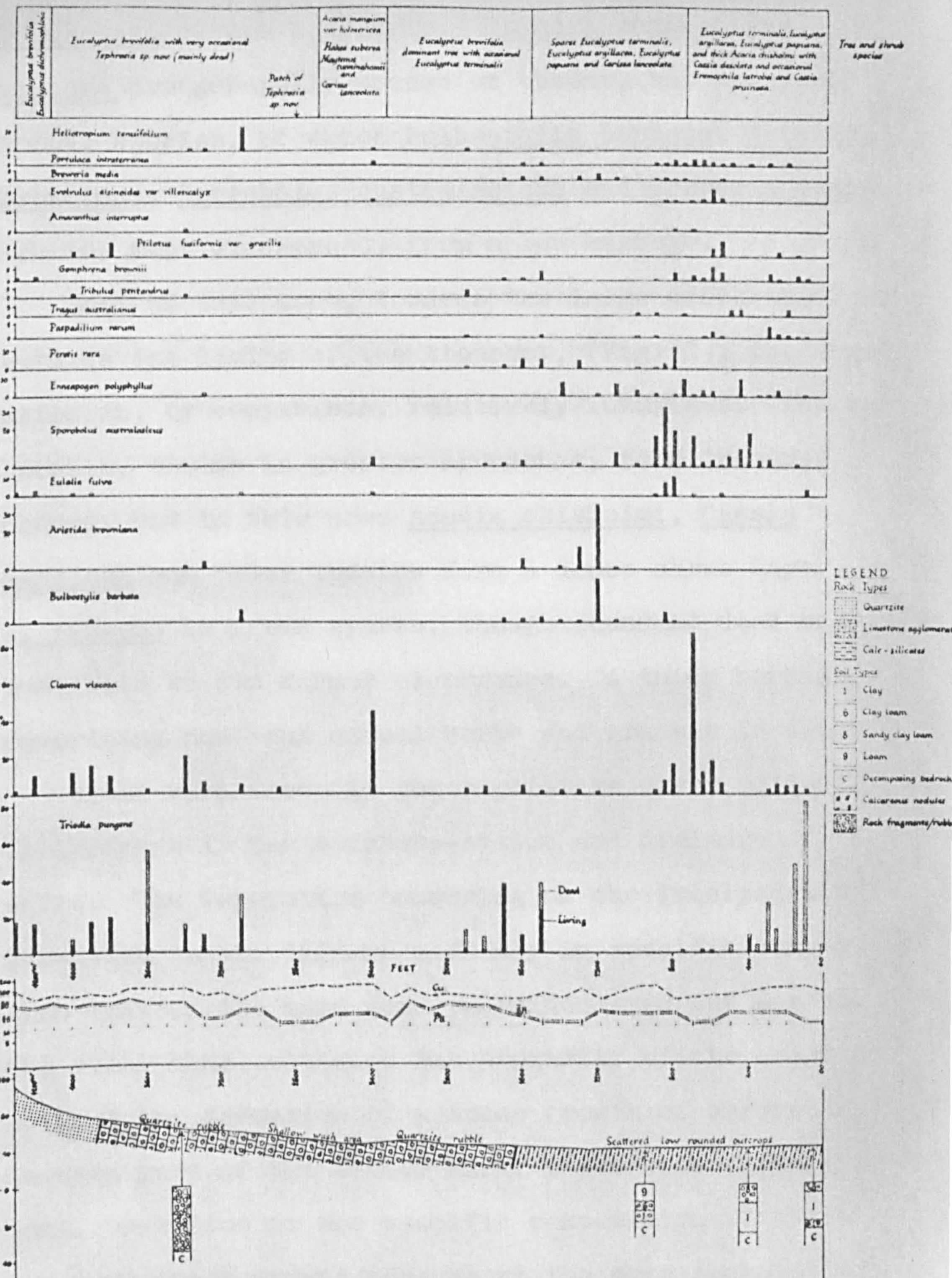


Fig. 9 Results of Transect 11, Area north-east of the Quartzite Range

lanceolata occurs sparingly. Triodia pungens and Cleome viscosa are generally sparse or absent, but numerous annual species, of which Bulbostylis barbata, Aristida browniana, Sporobolus australasicus and Breweria media are the most widespread, form a low herbage.

East of this zone, towards the large creek which lies outside the limits of the transect, (Fig. 8), the vegetation is, by comparison, relatively luxuriant. The same species, though in greater abundance, form the tree canopy, but in this area Acacia chisholmi, Cassia desolata and other species form a dense shrub layer. T. pungens is again sparse, though abundant dead material testifies to its former occurrence. A thick herbage, comprising numerous annual herbs and grasses is present.

These variations in the vegetative cover reflect differences in the moisture-status and drainage of the soils. The vegetation occurring on the freely-drained quartzite rubble differs markedly in specific composition from that on the more poorly-drained Arid Red Earths. On the other hand, although the proximity of the creek has allowed the formation of a dense growth of shrubs in the eastern part of the latter unit, there is a comparatively small variation in the specific composition of the tree and herbaceous strata throughout the zone occupied by these soils. This confirms the earlier observation that the intensity of a change in the environmental conditions governs the degree to which the corresponding vegetation units will also vary.

Although the geochemical results indicate above-threshold levels for copper throughout the greater part of the transect, (see Table 5), no enrichment is evident in the areas occupied by the species normally associated with mineralisation, Tephrosia sp. nov. and Bulbostylis barbata. Hence, in this region, the occurrence of the plants is apparently un-related to at least near-surface mineralisation in the bedrock.

(5). The Turkey Creek Area

(a). Introduction

In this area, lying some 6½ miles north of the Lode, (Fig. 2), Tephrosia sp. nov., Polycarpaea glabra, Eriachne mucronata and Bulbostylis barbata are associated with several linear belts of malachite-stained micaceous shales, (Fig. 10B and Plate 18).

The remainder of the area is largely underlain by steeply-dipping calc-silicates with a general north-south trend. These are variable in lithology, some consisting dominantly of mica while others are composed of quartz, calcite and plagioclase. In the north-east, the calc-silicates give way to quartzitic rock, apparently representing a shear zone. Smaller occurrences form low gravelly or rocky ridges within the calc-silicate outcrop, while a more extensive zone flanks the area in the south.

Erosion has prevented the development of any great depth of soil, and, over most of the area, this consists, at most, of a few inches of gravelly material. In the south-west, however, fine-textured soil of the Arid Red Earth type has developed on material presumably washed down from the high ground to the south.

The region is traversed by northward-flowing, deeply dissected creeks. These are separated by level or gently rounded interfluves.

(b). Tree and shrub cover

Fig. 10A indicates the mapped distribution of the dominant trees and shrubs. *Eucalyptus argillacea* is the most widespread species. In the central part of the area, it occurs with a fairly dense shrub cover of *Acacia chisholmi*, while, in the east, a large sector is occupied by an association comprising these two species and *E. terminalis*. This association is also developed on parts of the area occupied by the Arid Red Earth soils, the remainder of this zone being devoid of trees and shrubs. Similarly, over the main zone of copper staining, trees and shrubs are generally absent, apart from *Tephrosia* sp. nov.

E. brevifolia forms an open woodland on quartzitic bedrock in the north-west and over part of the southern half of the region. A shrub layer is normally absent,

Fig. 10 A,B Distribution of (A) the Dominant Trees and Shrubs, and (B) the Ground Vegetation in the Turkey Creek Area

but A. chisholmi may be abundant in places. Mixed stands of E. brevifolia - E. argillacea - E. terminalis and A. chisholmi are common where the two main associations meet.

(c). Ground vegetation

This is indicated in Fig. 10B, which also shows the distribution of the shrub Tephrosia sp. nov. Triodia pungens forms the dominant member of the herbaceous stratum over the bulk of the area. It occurs with Triodia longiceps in parts of the north-east and south-east of the region, while, in the south-west, it is replaced by a sparse growth of Sporobolus australasicus, on the Arid Red Earth soils.

The distribution of Polycarpaea glabra, Bulbostylis barbata and Eriachne mucronata shows a close correlation with the belts of outcropping malachite-stained shales in the western part of the area. On the other hand, Tephrosia sp. nov., while generally restricted in a living condition to the vicinity of these zones, is also represented by dead material over a wide, apparently barren, sector in the east.

(d). Discussion

The distribution of the more widespread plants in the Turkey Creek Area presents a relatively simple picture, and is apparently governed by variations in the drainage status and parent material of the soils.

Eucalyptus brevifolia favours the higher, better-drained regions while E. terminalis, E. argillacea and Acacia chisholmi tend to occur on lower ground. In part this may be correlated with variations in the nature of the residual soils which occupy the bulk of the region. The harder, more siliceous rocks which form the upland areas give rise to acidic soils. On the other hand, the more calcareous varieties of the calc-silicates, since they weather more easily, occur on lower ground and in these areas the soils tend to be consequently basic.

The Arid Red Earth soils which occupy the level plain in the south-west corner of the area are largely devoid of tree and shrub cover. A similar feature was observed in the Area north-east of the Quartzite Range, where it was suggested that the sparseness of the vegetation was related to the high clay content of the soils. This, combined with the low gradients, gives rise to poor drainage conditions. A large proportion of the rain water received during the wet season will probably remain in the upper soil horizons, and will be quickly lost by evaporation during the following dry season. Thus, insufficient water-supply during the rainless period may explain the absence of the deeper-rooted trees and shrubs, and the perennial grass T. pungens, from these sectors.

The malachite-stained shale in the western part of the area do not give rise to any marked relief feature. Likewise, the soils developed over the mineralised zone are outwardly similar to those on neighbouring, un-mineralised rocks. It appears, therefore, that the absence of trees or shrubs, apart from Tephrosia sp. nov., is associated with the high copper concentrations in the soils overlying and surrounding the mineralised zones.

Transect 12, which runs east-west across the southern part of the area, (Fig. 10B), illustrates the major variations in the vegetative cover. The open nature of the tree and shrub canopy on the Arid Red Earths at the western end of the transect is evident, (Fig. 11), while Sporobolus australasicus, Enneapogon polyphyllus, Aristida browniana and Tragus australianus form only a sparse herbage.

Over the greater part of the dissected region to the east the ground vegetation is dominated by T. pungens, Cleome viscosa and the low grass Eriachne pulchella. Eucalyptus argillacea, E. terminalis and E. brevifolia form a fairly close tree canopy, while Acacia chisholmi, though often dead, forms very thick cover in places.

Few clear-cut divisions can be made in the vegetation over this wide zone of calc-silicates. In part this is related to the lack of contrast in the relief. The geology also shows little marked variation, though a "quartz blow", or shear zone filled by quartzitic material,

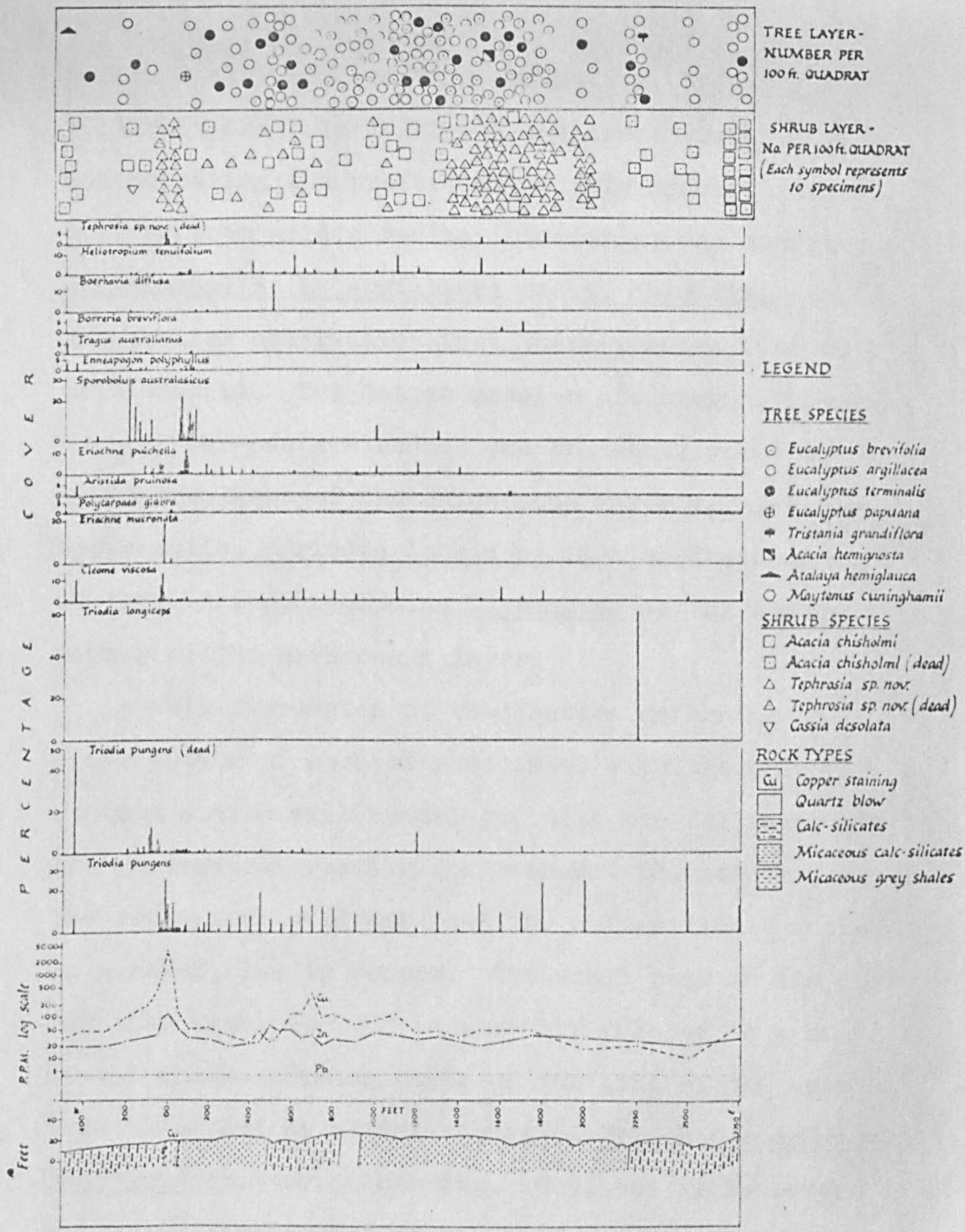


Fig. II Results of Transect 12, Turkey Creek Area outcrops at 900E. At this locality E. brevifolia is virtually the sole member of the tree stratum, again demonstrating the preference of this species for soils derived from acidic rocks. Similarly, the sparsity of E. terminalis, E. argillacea and A. chisholmi confirms the earlier observation that these species tend to avoid acidic soils. The latter species are common, however, towards the eastern end of the transect, where the calc-silicates, here of the calcareous variety, give rise to basic soils. Triodia longiceps is also frequent in part of this sector, replacing T. pungens as the dominant member of the herbaceous layer.

A full discussion of the factors governing the distribution of species associated with the malachite-stained shales will be delayed till the following section. The geochemical results for Transect I2, however, confirm the geological evidence that the calc-silicate rocks are, in general, low in copper. The small peak in the curve for this metal at 700E is probably related to a small zone of malachite-staining north of the line of the transect. This is marked by a small patch of Eriachne mucronata and Tephrosia sp. nov., (see Fig. 10B), but it is evident that the major development of the latter species in the zone traversed by Transect I2 is not associated with copper enrichment in the substrate.

(6). Conclusions

(i). The most widespread vegetation sub-formation occuring within the Dugald River Area is that of Low Tree and Shrub Savanna. Structurally this unit comprises an open cover of low trees, a discontinuous shrub layer, and a sparse to mid-dense herbaceous stratum, generally dominated by the coarse, xeromorphic hummock grass, Triodia pungens. The Thicket sub-formation is represented by scattered stands of Acacia cambagei, while Savanna Grassland is found on heavy clay soils on the flood plains of the major rivers.

(ii). Generally speaking, there is little species carry-over between these various sub-formations, though Acacia cambagei may occur as a sub-dominant in the Low Tree and Shrub Savanna. Within the latter unit, however, many species carry-over from one association to the next.

(iii). The boundaries between the areas occupied by different sub-formations are normally fairly abrupt, but gradational zones are common between the various associations of the Low Tree and Shrub Savanna.

(iv). The Eucalyptus brevifolia - E. dichromophloia - Triodia pungens association occupies well-drained, shallow, acid soils on the Quartzite Range.

(v). Well-drained, acid soils derived from shales and fragmental calc-silicates, and tracts of quartzitic rubble and gravel, carry an open woodland association of Eucalyptus brevifolia and Triodia pungens.

(vi). Hilly regions underlain by calc-silicates are normally occupied by the Eucalyptus brevifolia - Acacia chisholmi - Cleome viscosa association.

(vii). The association of Eucalyptus argillacea - E. terminalis - Acacia chisholmi - Triodia pungens, the most abundant in the region, occurs on fairly shallow, basic soils derived from limestones and calc-silicates. These tend to weather relatively rapidly, and hence the association is found on areas of low to intermediate elevation.

(viii). Low interfluves covered by Arid Red Earth soils, and fine-textured flood plain deposits, generally carry a fairly sparse association of Eucalyptus argillacea - E. terminalis - Carissa lanceolata and Sporobolus australasicus. The open nature of the tree cover and sparsity of Triodia pungens in this unit may be associated with the low gradients and high clay content of the soil. These factors induce poor drainage and a rapid loss of soil-water by evaporation during the dry season.

(ix). Thickets of Acacia cambagei are relatively common on the level interfluves and flood plains. Apart from these occurrences, however, the distribution of this association is restricted to isolated relicts of lateritic soils.

(x). The _Astrebla pectinata_ - _Iseilema macrathera_ tussock grassland occurs on low-lying clay soils which are probably subject to flooding during the wet season.

(xi). Tall _Melaleuca leucadendron_ and _Eucalyptus camaldunensis_ trees fringe the major rivers, where water is presumably available at shallow depth during the dry season. As the creeks diminish in size towards their source, these species die out and are replaced by the lower tree, _Tristania grandiflora_.

(xii). Those factors, primarily relief, drainage and the soil depth and texture, which govern the supply of water to the plant roots, appear to play a dominant role in the distribution of the major vegetation units in the Dugald River Area. Variations in the pH of the soil are also important, however, while low phosphorus and potassium contents may have a bearing on the distribution of _Acacia cambagei_.

(xiii). Although soil analyses, (see previous section), indicated variations in chemical content between soils occupied by different associations, variations within an area occupied by a given association were also common. This suggests that the factors mentioned under (xii) above have a greater influence on the distribution of the vegetation units than the concentration of the major or trace elements in the substrate.

SECTION C: DISTRIBUTION OF PLANT SPECIES ASSOCIATED WITH MINERALISATION

(1). Introduction

A survey of previous literature on the relationship between certain plants and mineralised deposits has been given in the Introduction to this thesis. The present investigation was aimed at establishing which plants were associated with the ore-deposits in the Dugald River Area, and which were the factors governing their distribution. Further, the study sought to ascertain whether these species, the "Indicator Plants", were only associated with certain types of ore-deposit or with mineralisation in general; whether they were restricted to a certain range of ore-metal concentration in the substrate; and finally, to assess their importance in mineral exploration for base-metals in the region.

The greater part of the field work was carried out in the Lode Area. Reference has already been made to the remarkable "cut-out" of the more widespread plants, which may be conveniently termed the background vegetation, over the ore-deposits. The background species are replaced by an assemblage comprising Tephrosia sp. nov., (Dugald R. MMC/DMJP No. 5), Polycarpaea glabra, Eriachne mucronata, Bulbostylis barbata and Fimbristylis sp., (Dugald R. MMC/DMJP No. 279).

A similar assemblage is associated with zones of copper mineralisation in the hangingwall shales of the Lode, and likewise on malachite-stained shales in the Turkey Creek Area. The distribution of the assemblage species was mapped, and the variations in the vegetation over the mineralised zones measured by means of transects. Changes in the soils along the transects were recorded from profile pits, and soil samples collected for major, spectrographic and geochemical analysis. A full description of the field techniques is given in Section A.

Finally, the distribution of the species was mapped throughout the entire Dugald River Area, and several geochemical traverses made across those occurrences where the plants were not associated with obvious mineralisation.

(2). <u>The Dugald River Lode Area</u>

(a). <u>The distribution of the species associated with mineralisation</u>

This discussion centres mainly on the shrub and herbaceous species, since, with the possible exception of <u>Eucalyptus terminalis</u>, none of the tree species show a direct affinity with the mineralised zones. In fact, as indicated in Fig. 3B, over the greater part of its outcrop the Lode is devoid of tree cover, (Frontispiece). This, together with the distinctive plant assemblage developed over the mineralised rocks, serves to distinguish this zone from the neighbouring, un-mineralised, areas.

Although the species comprising the Lode assemblage are most abundant over the known mineralised zones, they also have a scattered distribution in areas where mineralisation has not been proved, or is of low grade.

Thus, Eriachne mucronata is fairly common on the shales bordering the Lode, particularly in the south of the area, (Fig. 3C.). Many of these occurrences mark the site of pockets of low-grade copper or zinc mineralisation generally capped by ferruginous gossans. Moreover, comparison of the distribution of this species with that of copper and zinc in the soils of this sector, (Fig. 5), reveals a fairly close correlation between E. mucronata and minor copper and zinc anomalies.

Similarly, Tephrosia sp. nov. is associated with a minor copper anomaly near the 2500 N station on the Base Line, and Fimbristylis sp. occurs near a small zinc anomaly at 6000 N, (Figs. 3C and 5).

However, not all of these isolated occurrences can be related to mineralisation or to zones of metal enrichment in the near-surface soils. Thus Eriachne mucronata is found, albeit sparingly, on the barren quartzite and quartzite boulder conglomerate horizons in the west of the area, where the geochemical results indicate low values for copper, lead and zinc. Similarly, Tephrosia sp. nov. occurs on quartzite in the south-west, while Polycarpaea glabra and Bulbostylis barbata are both found along the beds of several creeks draining the Quartzite Range in the north-west. Again, soil and stream sediment analysis indicates low values for copper, lead and zinc in these areas.

Apart from one or two small patches of E. mucronata and Tephrosia sp. nov., none of the species characteristic of the Lode assemblage occur in the vicinity of the small copper showings in the western band of calc-silicates, (Fig. 3A). The deposits are of relatively low grade, however, and, generally speaking, only minor copper anomalies are developed in the overlying soils, (Fig. 5). Moreover, these soils are frequently calcareous and, as will be described later, the species of the Lode assemblage tend to avoid this type of environment.

Over the greater part of its length, the Lode assemblage is dominated by the species Eriachne mucronata, Polycarpaea glabra and Bulbostylis barbata, (Figs. 12 and 13). In the south, the assemblage occupies the pronounced ridge of the hangingwall shales, (Fig. 4A), which here contain sporadic copper mineralisation. On the other hand, the Lode, here poorly-developed and of low grade, is marked only by scattered clumps of Bulbostylis barbata. As the grade of the ore increases to the north and the copper mineralisation in the hangingwall gives way to barren shales, there is a corresponding "cross-over" of the assemblage from the hangingwall to the Lode zone. Examination of Fig. 5 indicates that this "cross-over"

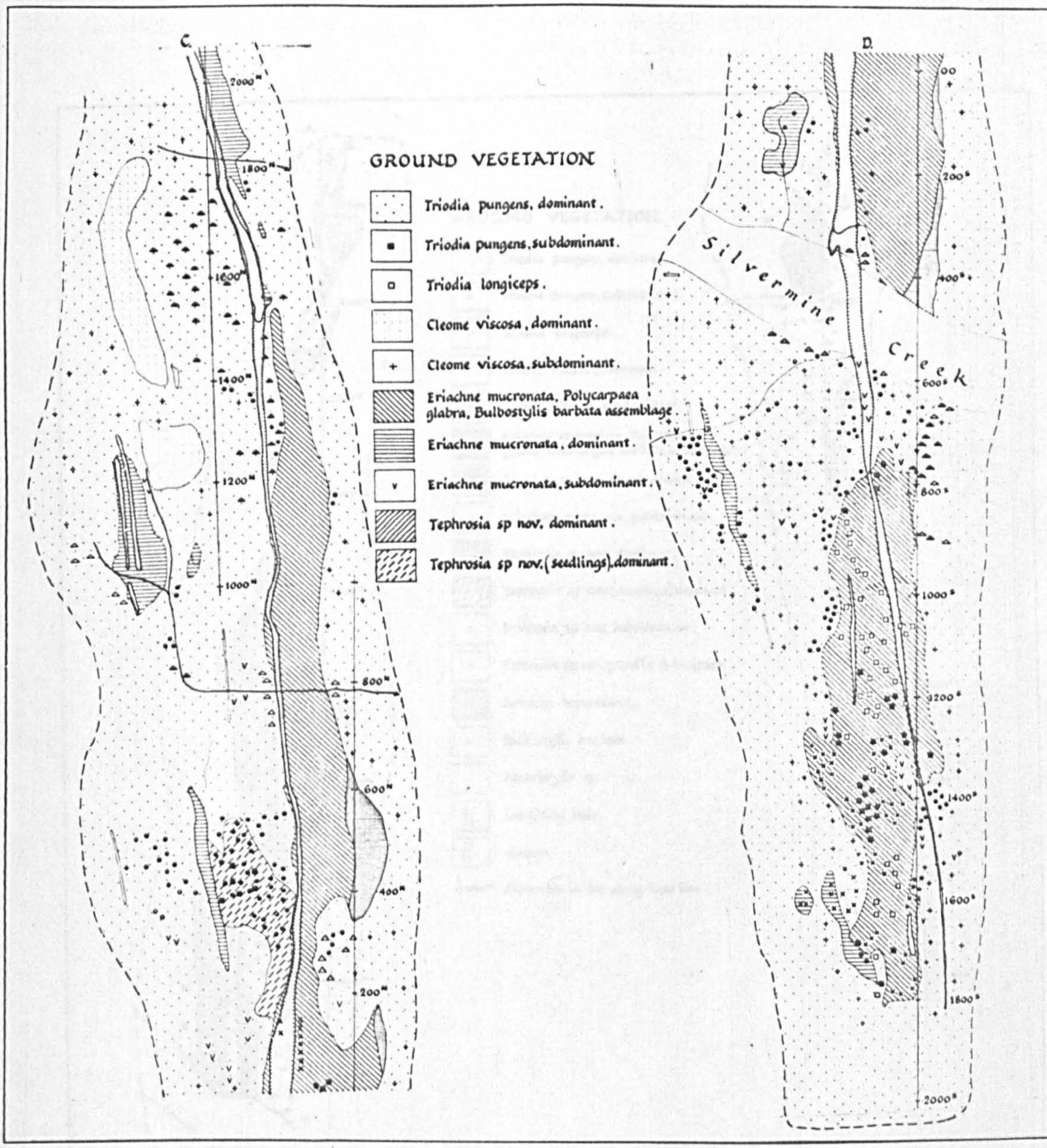


Fig. I2 Distribution of Herbaceous Species over the Southern Half of the Lode Outcrop, (for remainder of Key, see Fig. I3)

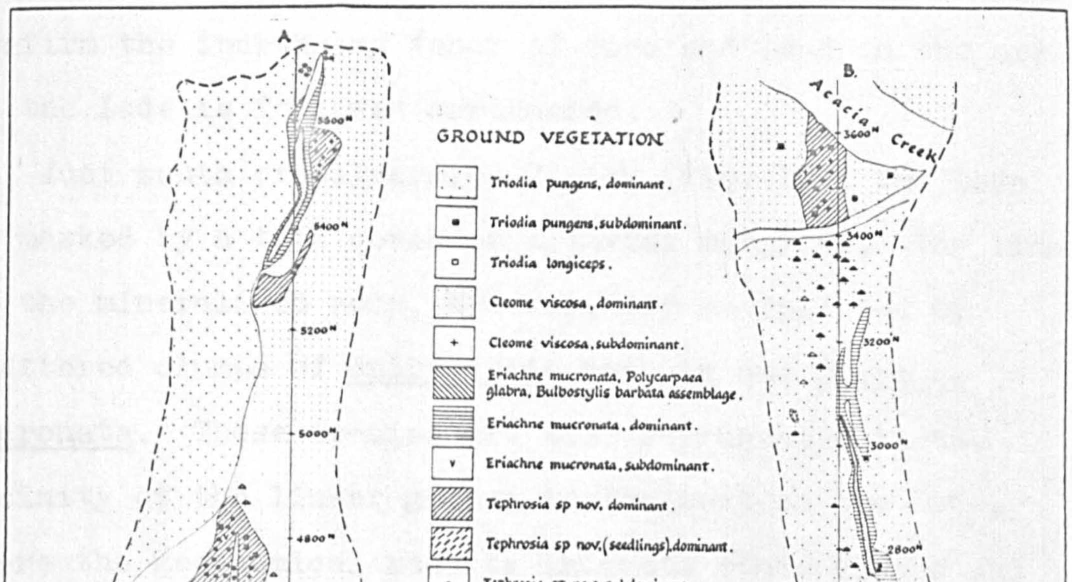


Fig. I3. Distribution of Herbaceous Species over the Northern Half of the Lode Outcrop.

follows closely that of the soil copper anomaly, which in the south is developed over the hangingwall but further north occurs over the Lode. The geochemical results also confirm the increasing tenor of zinc and lead in the ore as the Lode is followed northwards.

Just south of Silvermine Creek, (Fig. 12), the Lode is masked by a thin cover of alluvial material. The line of the mineralised zone, however, may be followed by scattered clumps of Bulbostylis barbata and Eriachne mucronata. These species are also represented in the vicinity of the linear gossan to the west of the Lode, where the geochemical results indicate minor copper and zinc anomalies, (Fig. 5).

The distribution of Tephrosia sp. nov. in this region is also interesting. The shrub occurs on the banks of Silvermine Creek and along the small northward-flowing tributary which drains the Lode zone. Its distribution in this sector of the Lode is therefore restricted to these areas of low elevation, deeper soil and, presumably, increased water supply. Thus, its absence from the higher ground to the south may be related to the shallow, well-drained nature of the soils.

To the north of Silvermine Creek, the shales enclosing the Lode give rise to a pronounced relief feature, (Fig. 4A and Frontispiece), breached in places by small eastward-flowing creeks. The Lode itself lies in a small depression between two parallel ridges formed by the hangingwall and footwall rocks. The former ridge is the less pronounced of the two, and further north dies out altogether as a topographic feature.

In this sector the position of the Lode assemblage has shifted further to the east and now occupies the Lode and footwall, forming a linear belt which extends northwards for about 2000 feet without any interruption. From 400 S to 1600 N, the assemblage comprises the species Eriachne mucronata, Polycarpaea glabra and Bulbostylis barbata, while Fimbristylis sp. has a sparse distribution at the southern end. E. mucronata also occurs on gossanous shales between 300 and 600 N, and over the outcrop of the West Lode from 1000 to 1300 N. B. Barbata is fairly common on the shales bordering the mineralised zone, while Tephrosia sp. nov. is found along the small creeks which traverse the Lode, as at 800 N. It is also found in seedling form, however, over a fairly extensive area on the hangingwall shales between 200 and 300 N, (Plate 17), while further north abundant dead stalks and branches testify to its former, more widespread, distribution.

Examination of Fig. 5 indicates that the soils develope on the footwall shales are appreciably richer in zinc and lead than those on the hangingwall. Copper, on the other hand, forms minor anomalies on the hangingwalls of both the Main and Western Lodes. It is apparent, therefore, that the Lode assemblage, largely confined to the footwall rocks, occupies the zone of maximum zinc and lead enrichment in the near-surface soils of the region.

Within the sector from 1600 N to Acacia Creek, (Fig. 13), the width of the assemblage decreases markedly and its distribution becomes more sporadic. Its character also changes, with Polycarpaea glabra and Bulbostylis barbata largely dying out to leave a mono-specific community of Eriachne mucronata. This forms a narrow belt over the low ridge of the footwall rocks. In places the Lode lenses out, with a concomitant decrease or absence of E. mucronata and a fall in the level of lead and zinc in the near-surface soils, (Fig. 5). Tephrosia sp. nov. is again represented by numerous dead stalks and branches on the hanging-wall shales.

The Lode is masked by coarse quartzitic alluvium, one to two feet in thickness, on the low interfluve between Acacia Creek and its southern tributary. Its course, however, may be followed by a fairly dense growth of Tephrosia sp. nov., with scattered patches of Bulbostylis barbata. Tephrosia sp. nov. is also common north of the creek, forming a belt about 1000 ft. long and 200 ft. wide over the narrow gossan marking the Lode outcrop. B. barbata is largely restricted to the immediate vicinity of the gossan while, apart from one or two isolated occurrences, Eriachne mucronata is absent.

Between 4900 and 5300 N, the Lode dies out on the surface, with a corresponding decrease in the level of lead and zinc in the soils, (Fig. 5), and absence of the Lode assemblages. From 5300 to 5700 N, however, the Lode again outcrops and the geochemical results indicate zinc, lead and copper anomalies in the overlying soils. Eriachne mucronata forms a linear belt on the narrow Lode gossan, while patches of Tephrosia sp. nov. and Bulbostylis barbata occur on the neighbouring shales.

(b). Factors influencing the distribution of the species

From the results of the mapping and quantitative measurement of the large-scale variations in the vegetative cover of the Dugald River Area, and likewise in those areas studied in detail, it appears that the distribution of the more widespread plant species is largely governed by the factors of relief, drainage, soil depth and texture, and the pH of the soil.

The investigations in the Lode area, however, seem to discount these factors as a major influence on the distribution of the species associated with mineralisation. For example, the Eriachne mucronata, Polycarpaea glabra, Bulbostylis barbata assemblage is equally extensive where the Lode shales form a ridge as where they form no pronounced relief feature. This is well illustrated by comparison of Transects 2 and 3, (Figs. 14, 15). In the former, the assemblage occurs over the high ridge formed by the

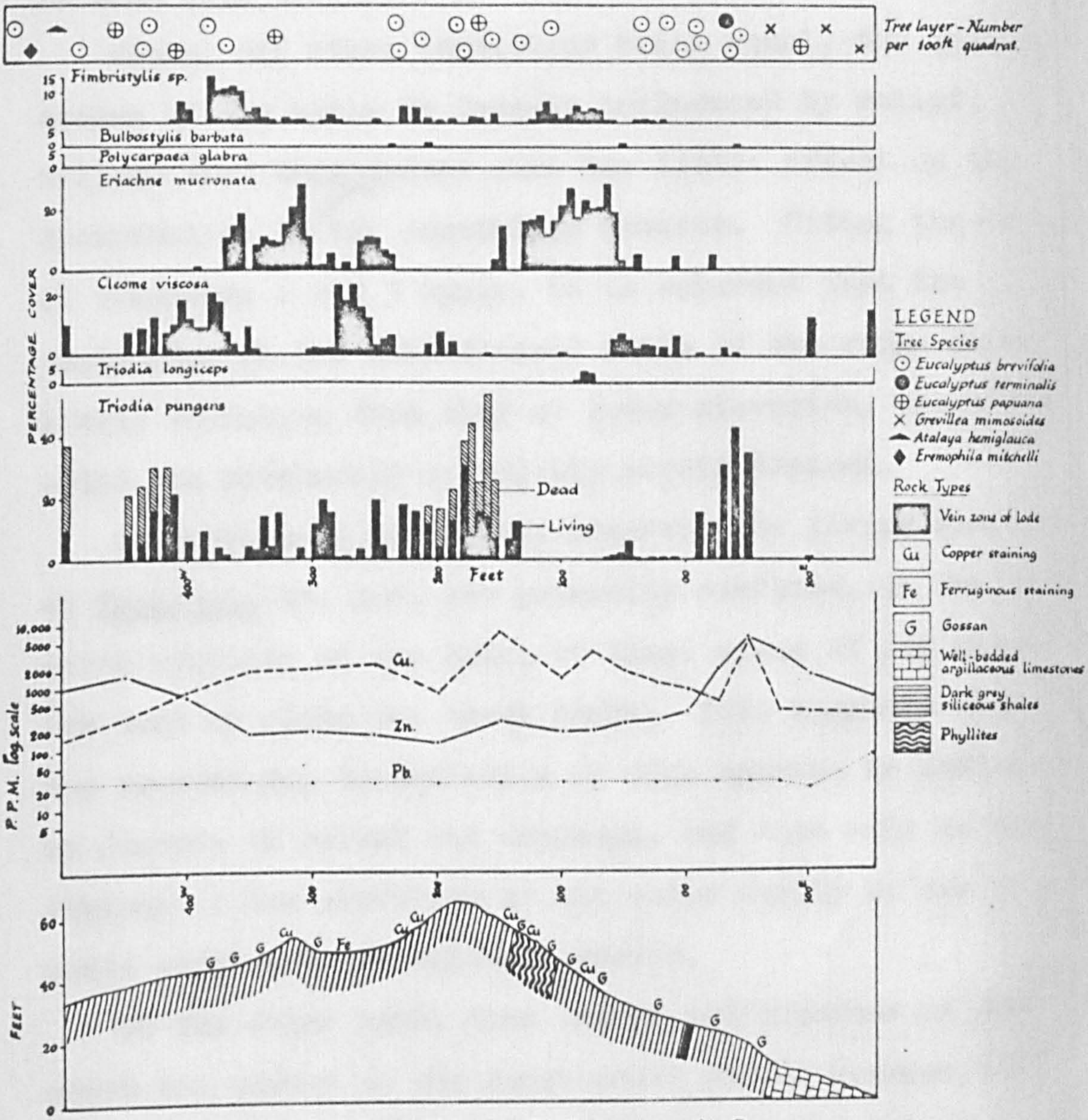


Fig. I4 Results of Transect 2, Dugald River Lode Area

copper-bearing hangingwall shales. On Transect 3, however, the species of the Lode assemblage are equally abundant over the mineralised rocks although the relief is much less pronounced.

Since, all other conditions being equal, the drainage-status of the soils is largely influenced by relief, it follows that this factor also has little effect on the distribution of the assemblage species. Citing the example of Transects 2 and 3 again, it is apparent that the assemblage on the well-drained soils of the ridge shows little variation from that at lower elevation, where the soils are presumably relatively poorly-drained.

As previously mentioned, however, the living specimens of _Tephrosia_ sp. nov. are generally confined, in the immediate vicinity of the Lode, to those areas of low elevation such as along the creek banks. This suggests that the present-day distribution of this species is influenced by factors of relief and drainage, and that only in those regions of low elevation is the water supply to the plant roots sufficient to maintain growth.

On the other hand, dead stalks and branches of the shrub are common on the hangingwall shales between 1200 and 3400 N, where the shales form the western flank of the pronounced Lode ridge.

This contrast between the different sites occupied by living and dead specimens of _Tephrosia_ sp. nov. is well

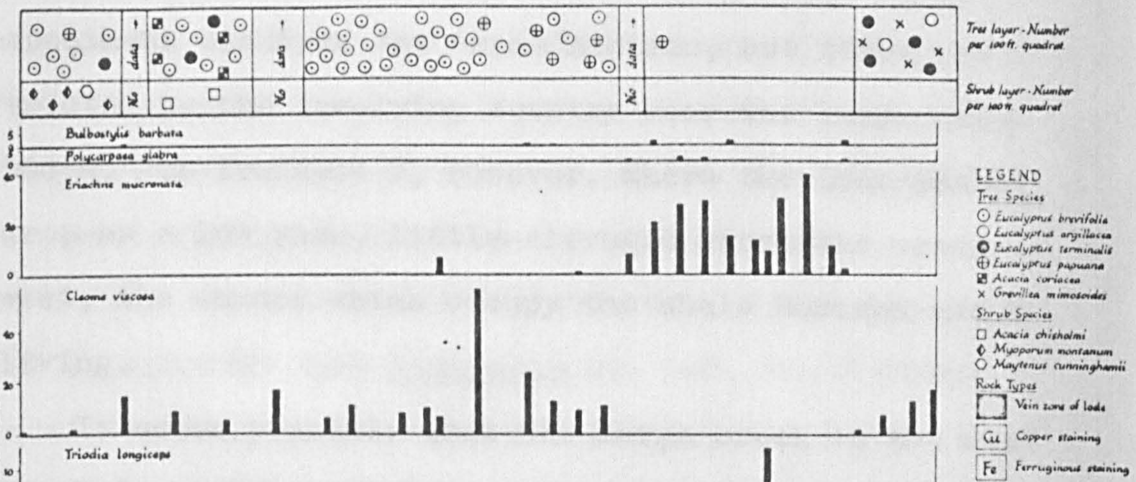


Fig. I5 Results of Transect 3, Dugald River Lode Area

illustrated by comparison of Transects 6 and 7, (Fig. 18, 19). In the former, which crosses the Lode zone at 2600 N, dead material is abundant on the shales west of the Lode, which here forms a pronounced feature. A few living specimens occur on the shale horizon, but these are restricted to the low-lying country near the large creek at 500 W. On Transect 7, however, where the Lode shales outcrop as a low rise, little-elevated above the creek to the west, the shrubs which occupy the shale horizon are all living.

It seems possible that the large creek to the west of the Lode on Transect 7 may give rise to a localised perched water table. Moreover, during the dry season, the water table in the regions of upland topography will probably sink at a faster rate than in the low-lying areas, due to the lateral flow of water from high to low ground through the soil and weathered rock. It would follow, therefore, that the supply of water to plant roots will be maintained for a longer period after the cessation of the wet season in the low-lying regions, where, as we have seen, Tephrosia sp. nov. is most abundant, than in the upland areas.

At this stage attention may be drawn to the occurrence of both dead and living shrubs on the low ridge of quartzitic limestone agglomerate east of the Lode on Transect 6, (Fig. 18). Although mineralisation was not observed at this locality, the geochemical results indicate a minor copper anomaly in the soils over the agglomerate horizon. The precise reason for the abundance of living specimens here, and their paucity on the hangingwall shales to the west, is unclear. Although the soils on the agglomerate ridge are shallow, and therefore presumably well-drained, it is possible that the lower elevation of the ridge compared with that of the Lode shales has allowed an increased supply of water to the plant roots.

From the widespread distribution of the dead material, it is apparent that Tephrosia sp. nov. was formerly much more abundant on the shales bordering the Lode. Taking into account the fact that at the present day the shrub is largely confined to the low-lying areas of favourable water-supply, it seems probable that the reason for its death over the greater part of the upland regions lies in the drought conditions which prevailed during the years prior to the present study, (Table 1).

There is evidence, however, that regeneration is now taking place. Thus at 400N, (Fig. 12), small seedlings of Tephrosia sp. nov. were found over quite an extensive area of the ridge formed by the hangingwall shales, (Plate 17). This suggests that, in time, the shrub will regain its former abundance on the shales bordering the Lode. It follows that, given normal amounts of rainfall for this part of Queensland, Tephrosia sp. nov. may survive equally well on sites markedly different in relief

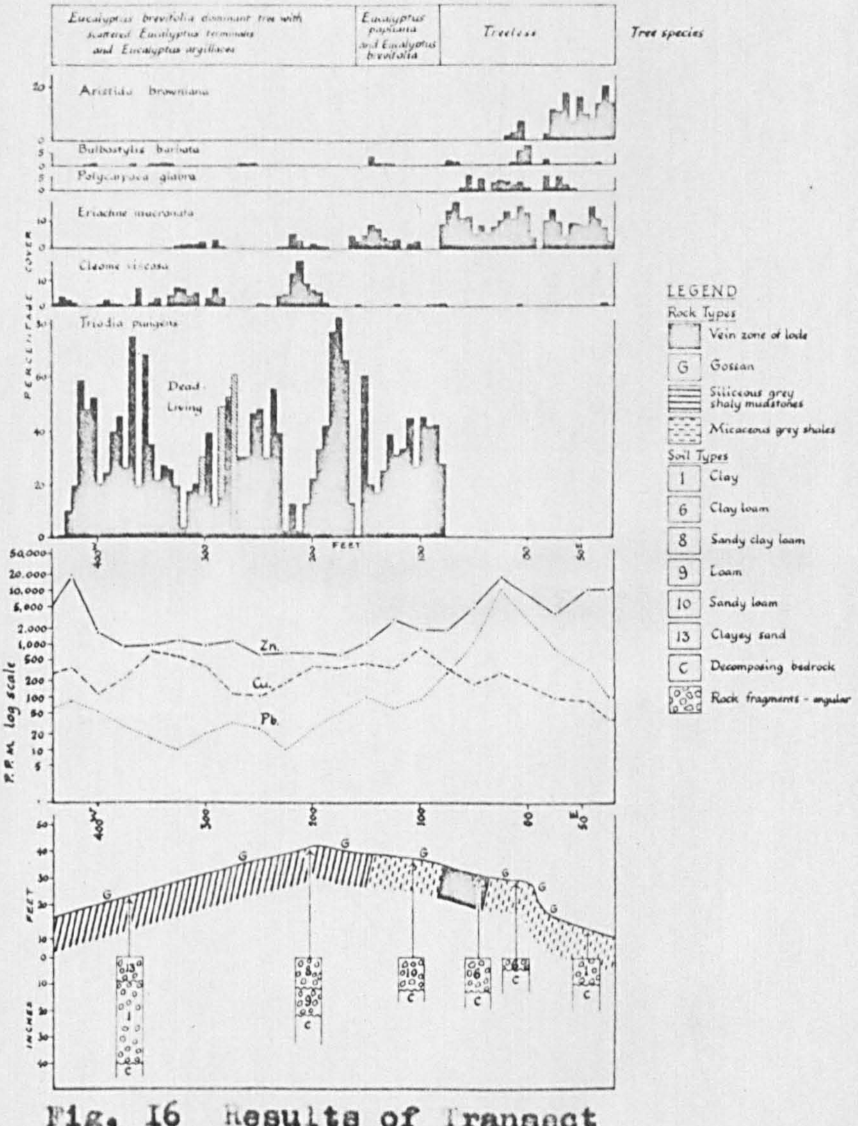
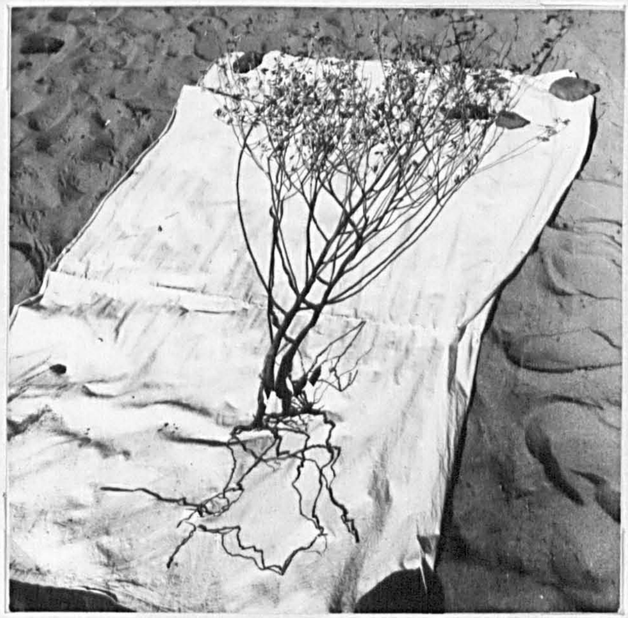


Fig. 16 Results of Transect 4 (Central), Dugald River Lode Area

Plate I6 Tephrosia sp. nov. (Dugald R. MMC/DMJP No. 5)

Plate I7 Tephrosia sp. nov. seedlings on the Lode Hangingwall



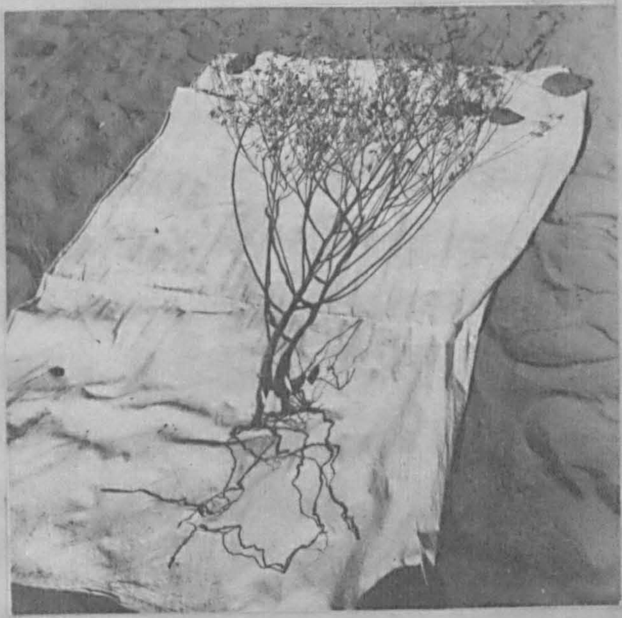


Plate I6 *Tephrosia* sp. nov. (Dugald R. MMC/DMJP No. 5)

Plate I7 *Tephrosia* sp. nov. seedlings on the Lode Hangingwall and drainage, and that these factors are not the principal ones governing its distribution.

The transect data also seems to discount soil depth or texture from having an important influence on the extent of the Lode assemblage. Along the greater part of the Lode outcrop, the soils developed over the shale horizons are of residual origin, (Fig. 4B). Generally they consist of a few inches of shale gravel in a sparse, fine-textured matrix. From Transects 4 and 5, (Figs. 16, 17), it is apparent that there are no major differences in soil depth or texture between the zone occupied by the Lode assemblage and that occupied by the background vegetation.

Where, however, the shallow residual soils give way to deeper alluvial material, as on the south bank of Silvermine Creek, (Fig. 12), there is a significant change in the herbaceous vegetation over the mineralised zone. The Lode assemblage is replaced by the normal background vegetation, although Eriachne mucronata and Bulbostylis barbata are still common and serve to delineate the sub-outcropping Lode.

At the second locality where the Lode zone is covered by alluvial material, on the interfluve between Acacia Creek and its southern tributary, (Fig. 13), the character of the Lode assemblage shows a striking change. The monospecific community of Eriachne mucronata, which occupies the shallow soils over the footwall ridge to the south,

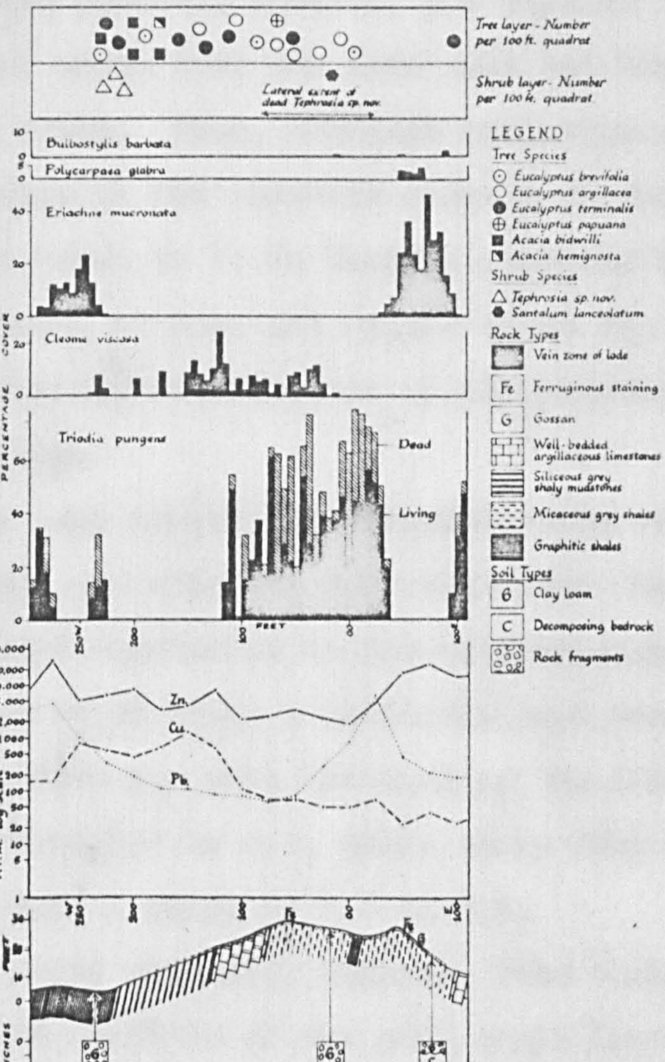


Fig. I7 Results of Transect 5, Dugald River Lode Area

gives way to an assemblage of Tephrosia sp. nov. and Bulbostylis barbata on the coarse alluvium which masks the Lode.

These species, however, are equally abundant on the residual soils over the Lode zone and footwall north of Acacia Creek. Thus, although soil type may cause slight variations in the specific make-up of the Lode assemblage, or even cause it to be largely replaced by the background vegetation, it does not appear to be the major factor governing the distribution of the species comprising the assemblage.

The Lode assemblage occupies soils which, generally speaking, are slightly more acid than those underlying the background vegetation on the neighbouring shales. Thus, examination of Table 4 indicates that the pH in soil samples from the area occupied by the Lode assemblage ranges from 5.6 to 6.2, while those from un-mineralised shales show a range of 6.0 to 6.6.

It seems unlikely, however, that such a small variation in the acidity of the soil could lead to the abrupt change in the vegetation as occurs over the mineralised zone. On the other hand, it appears that large variations in soil pH may have an important effect on the distribution of the species associated with mineralisation. The geochemical results on Transect 7, (Fig. 19), indicate a copper anomaly on the western limestone agglomerate

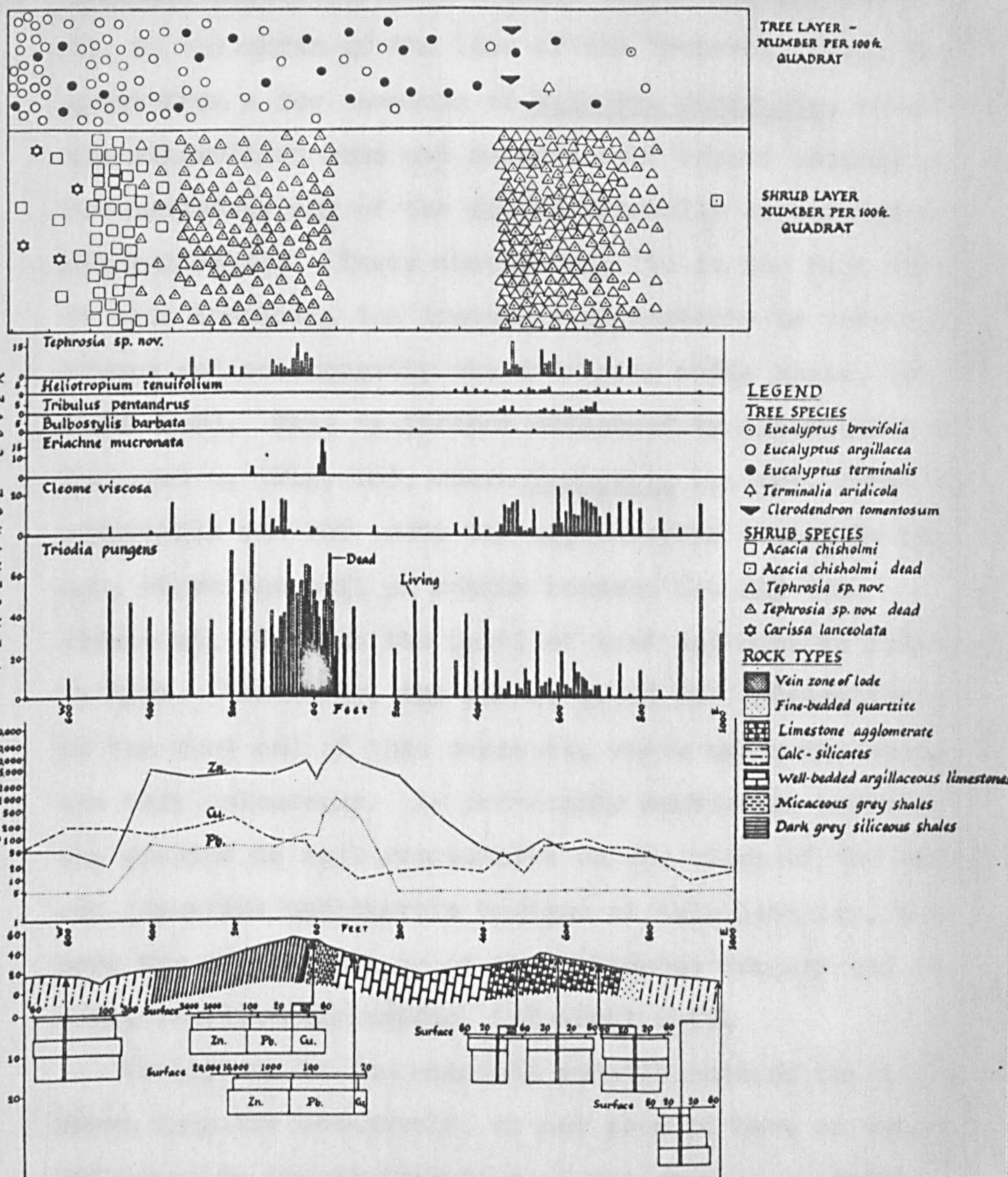


Fig. 18 Results of Transect 6, Dugald River Lode Area

horizon, associated with a small copper showing about 150 ft. to the north of the line of the Transect, (Fig. 3A). Apart from a few tussocks of Eriachne mucronata, however, the mineralised zone and related soil copper anomaly is not marked by any of the species normally associated with mineralisation. Their absence may lie in the fact that, at this locality, the limestone agglomerate is very calcareous and consequently the overlying soils basic, (pH about 7.2). This is further evidenced by examination of Transect 6, (Fig. 18), where Tephrosia sp. nov. shows a remarkable cut-out over the argillaceous limestone horizon, where the soil pH ranges between 6.4 and 7.6, (Table 4), although the level of lead and zinc is relatively high. Similarly, the shrubs avoid the calc-silicates at the west end of this transect, where again the soils are very calcareous. As previously mentioned, however, the species is well represented on the ridge of the eastern limestone agglomerate horizon at this locality, but here the agglomerate is of the siliceous variety and the soils consequently acidic, (pH about 5.6).

Variations in the chemical constituents of the soil, apart from the ore-metals, do not seem to have an important influence on the distribution of the species associated with mineralisation. Although the majority of the soil samples from the Lode and footwall are enriched in phosphorus compared with the general level of this element in

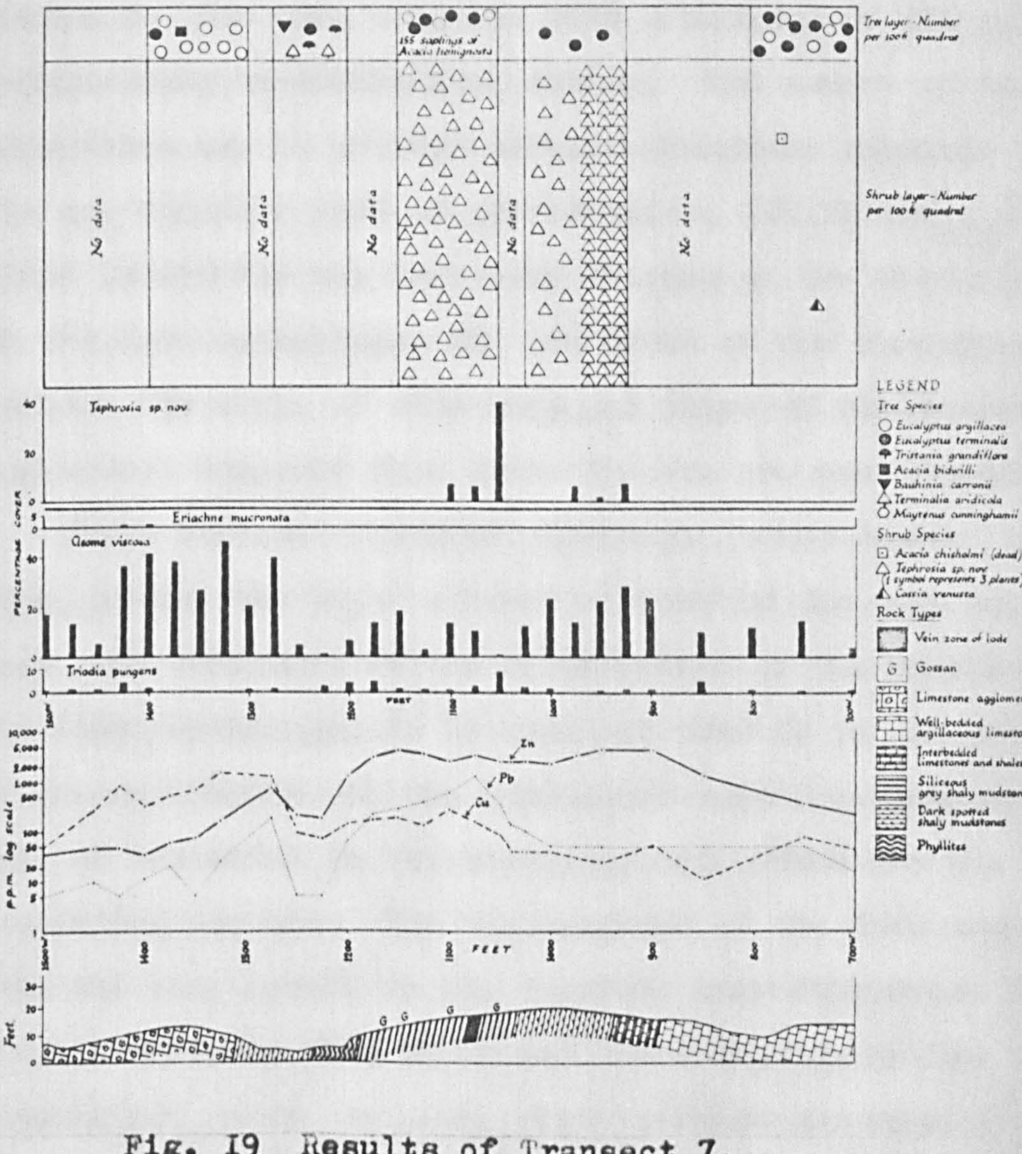


Fig. I9 Results of Transect 7, Dugald River Lode Area

the soils of the region, (Table 4), some samples from un-mineralised localities are also high. Thus the maximum value in soil samples from the Lode or bordering graphitic shales is 1500 ppm, compared with a maximum of 830 ppm on neighbouring un-mineralised shales. The source of the phosphorus may be primary metallo-phosphate minerals in the ore-deposit, such as pyromorphite, ($Pb_5Cl\ (PO_4)_3$). While phosphorus may have some bearing on the distribution of the Lode assemblage, the low order of the variation between the soils of this zone and those of the background vegetation suggests that other factors are more important.

While factors of relief, drainage, water-supply, soil type, pH and the major element content in the soil may have some influence on the distribution of the species of the Lode assemblage, it is apparent that it is the presence of mineralisation and the consequent anomalous concentrations of ore-metal in the overlying soil which are the overriding factors. The "cross-over" of the Lode assemblage from the hangingwall to the footwall near Silvermine Creek affords evidence that it is not the lithology of the mineralised rocks, as such, which governs the distribution of the species comprising the assemblage, but rather the associated high metal concentrations in the rooting medium.

This may be further illustrated by comparison of Transects 8 and 9, (Figs. 20, 21). In the former, the Lode outcrops as a narrow gossan and the level of lead and zinc

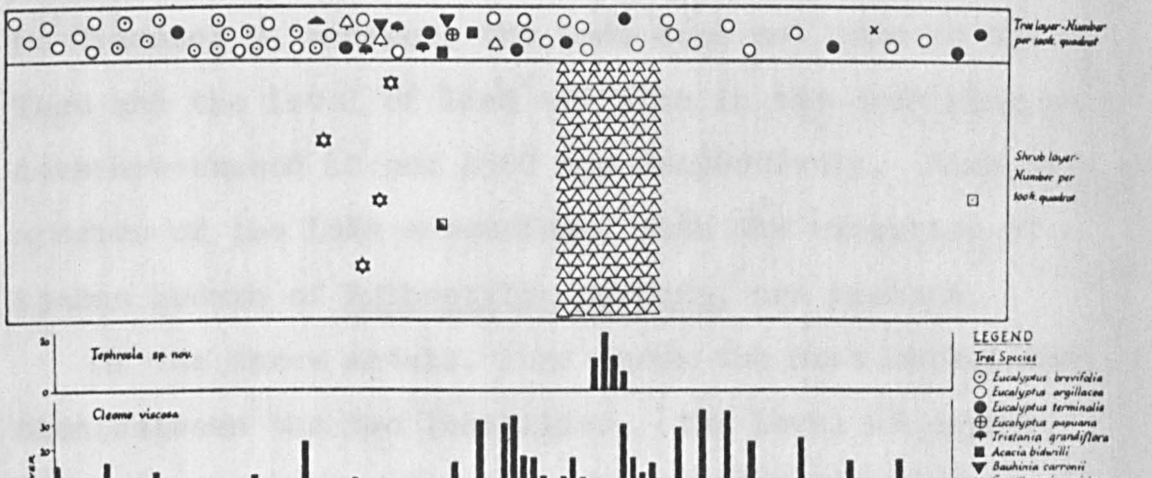


Fig. 20 Results of Transect 8,
Dugald River Lode Area

in the near-surface soil is in consequence relatively high, attaining maxima of 300 and 3000 ppm respectively. Tephrosia sp. nov. is abundant over the Lode and footwall, though other members of the Lode assemblage are absent. On Transect 9, however, the Lode does not come to the surface and the level of lead and zinc in the overlying soil does not exceed 10 and 1500 ppm respectively. None of the species of the Lode assemblage, with the exception of a sparse growth of Bulbostylis barbata, are present.

Of the three metals, lead shows the most marked variation between the two localities, (the level of copper being of the same order on both transects), suggesting that lead may have a more important influence on the distribution of the Lode assemblage than zinc.

This is further borne out by comparison of Transects 4 and 6, (Figs. 16, 18). On Transect 4, where the lead content in the soils over the footwall attains a level of 6000 ppm, the assemblage of Eriachne mucronata, Polycarpaea glabra and Bulbostylis barbata is about 140 ft. in width. On Transect 6, however, the lead concentration in the soils does not exceed 800 ppm, and the assemblage is only 20 ft. wide. The decrease in zinc between the two localities is much smaller, falling from a maximum of 20,000 ppm on Transect 4 to 15,000 ppm on Transect 6.

Transect 4 also shows that the "cut-out" between the background vegetation and the Lode assemblage occurs at the

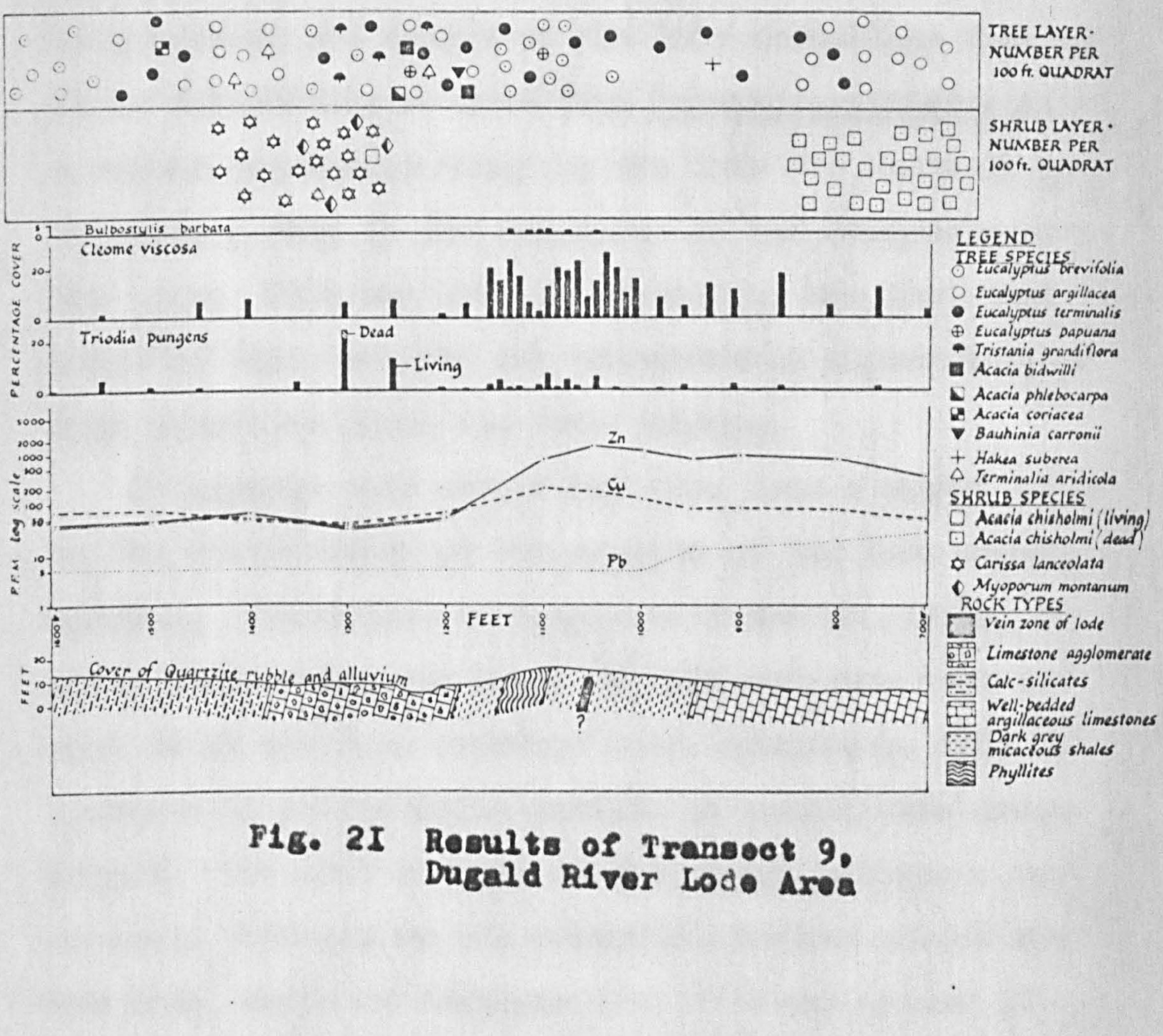


Fig. 21 Results of Transect 9, Dugald River Lode Area

point where the soil lead content begins to increase rapidly towards the peak of the anomaly on the footwall. While the level of zinc also rises in the soils occupied by the assemblage, the increase across the boundary between the two vegetation types is much less striking. This again indicates that lead may play a more important role in governing the extent of the Lode assemblage than zinc. It is interesting to note that Polycarpaea glabra attains a higher percentage cover on the Lode and footwall in Transect 4 than in the remainder of the transects across the Lode. This may also be related to the fact that the soils at this locality are considerably richer in lead than elsewhere along the Lode outcrop.

It appears that copper may also have a marked effect on the distribution of the species of the Lode assemblage, however. Comparison of Transects 8 and 10, (Figs, 20, 22), shows that, while the level of lead and zinc over the Lode zone is of the same order at both localities, only on Transect 10 do the soils contain an appreciable amount of copper. The soil content of this metal attains a maximum of about 2000 ppm on the malachite-stained shales west of the Lode, while on Transect 8 it does not exceed 100 ppm throughout the transect. While Tephrosia sp. nov. has a similar distribution and abundance over the mineralised zone on both transects, only at the site of Transect 10 do Eriachne mucronata and Bulbostylis barbata replace the

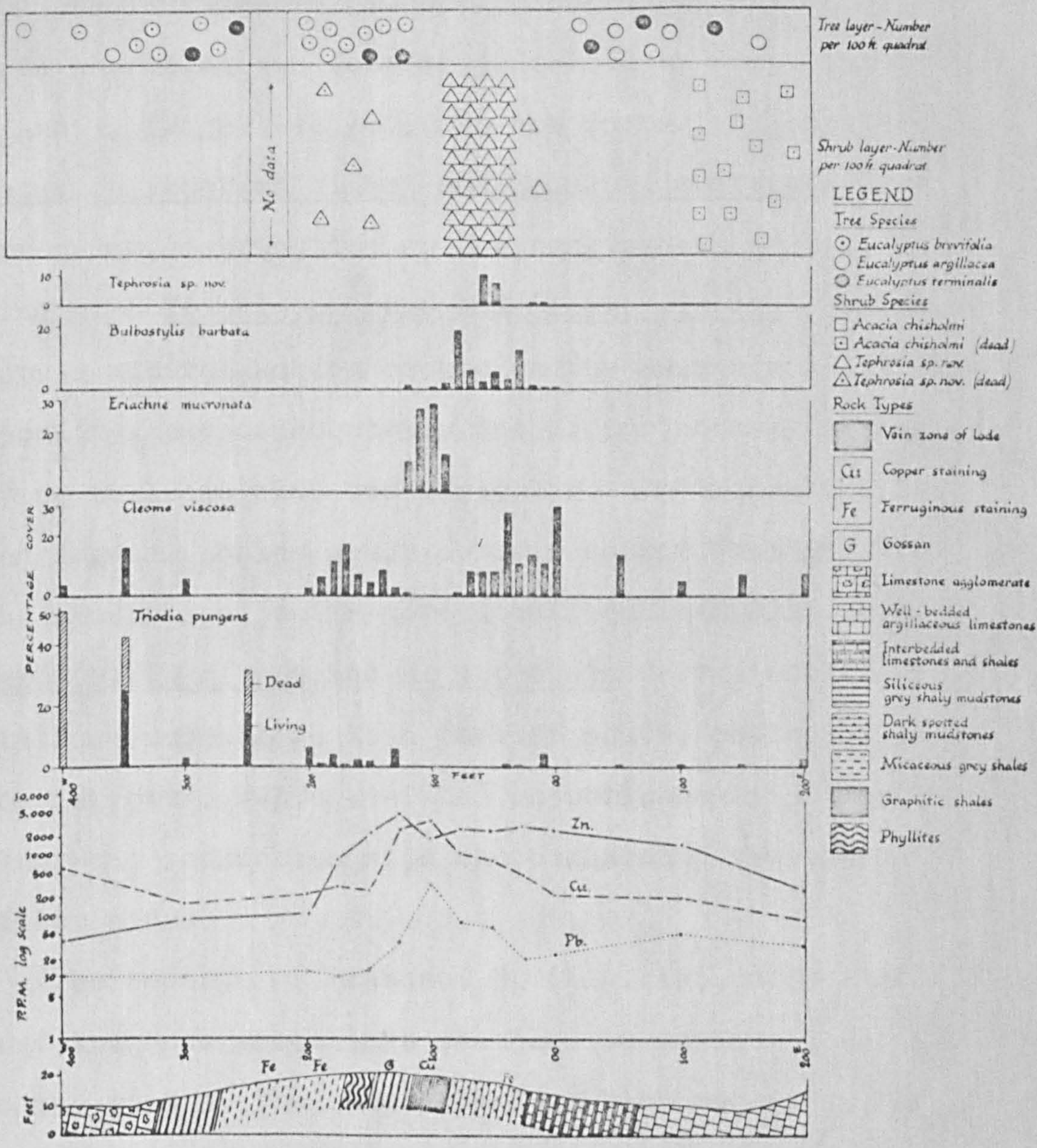


Fig. 22 Results of Transect IO, Dugald River Lode Area

background vegetation of Triodia pungens and Cleome viscosa.

The influence of copper on the distribution of the Lode assemblage is further evidenced by comparing Transects 2 and 3, (Figs. 14, 15). In the former, Bulbostylis barbata, Polycarpaea glabra and Eriachne mucronata have an irregular distribution on the hangingwall shales, occurring with Triodia pungens and Cleome viscosa. Disseminated copper mineralisation occurs in the hangingwall at this locality, and consequently the copper anomaly in the overlying soils is wide and irregular. On Transect 3 the hangingwall shales again contain copper, but in this case the mineralisation is more localised. At this site, B. barbata, P. glabra and E. mucronata form a much more distinct assemblage than further south, co-incident with the narrower, better-defined copper anomaly and having clear-cut boundaries with the background vegetation on either side.

The results of Transect 3, (Fig. 15), also indicate that the Lode assemblage reaches its maximum development to the west of the zinc anomaly, which occurs on the footwall near the boundary with the background vegetation. This may suggest that excessive amounts of this metal have little effect on the distribution of the Lode assemblage. Examination of Transect 5, (Fig. 17), however, indicates that the Lode assemblage on the footwall of the Main Lode is co-incident with the peak of the zinc anomaly in the soils, but slightly to the east of that for lead. The latter anomaly is marked only by the absence of Cleome viscosa from the background vegetation, which here extends eastwards across the Lode.

This transect also illustrates the occurrence of Eriachne mucronata on the West Lode, which outcrops at 225 W. At this locality the grass forms a distinct community, slightly east of the peak of the zinc anomaly, which here, however, co-incides with that for lead.

It is apparent, therefore, that high soil concentrations of copper, lead or zinc have a marked influence on the extent of the Lode assemblage. Examination of the transect data, however, indicates that the background vegetation can withstand considerably higher levels of zinc in the rooting medium than either copper or lead. The results of plant analyses, (Section D), also show that plants can absorb considerably greater quantities of zinc than the other two metals. Of the three elements, therefore, zinc seems to have the least effect on the distribution of the species of the Lode assemblage.

There is little evidence that individual species show a direct affinity with, for example, copper mineralisation and not for lead-zinc. Fimbristylis sp., however, is most abundant at the southern end of the mineralised zone, where the soils are rich in copper but low in lead and zinc, (Figs. 5, 12). It may be that this species shows an affinity with areas where the soils are rich in copper, but it was not observed in the vicinity of other areas of copper mineralisation. Moreover, the plant also occurs, though to a limited extent, on the Lode footwall just to the north of Silvermine Creek, where the soils are high in lead and zinc but relatively low in copper.

Certain members of the Lode assemblage, however, seem to be able to withstand higher concentrations of ore-metal in the soil than others. At the present day, Tephrosia sp. nov. is largely confined, in the immediate vicinity of the Lode, to the northern end where the soils are relatively low in lead and zinc compared with further south. Although dead stalks and branches were found on the hangingwall shales south from Acacia Creek, none was observed on the footwall where the level of lead and zinc generally attains its maximum. Thus, while Eriachne mucronata, Polycarpaea glabra and Bulbostylis barbata, and to a limited degree, Fimbristylis sp., can all survive on soils exceedingly rich in lead and zinc, Tephrosia sp. nov. seems unable to do so. Moreover, evidence from the Turkey Creek Area indicates that the plant also avoids these areas where the soils contain very high concentrations of copper.

Although Eriachne mucronata, Polycarpaea glabra and Bulbostylis barbata all occur in localities where the soils are low in copper, lead and zinc, these species are confined to a narrower range of ore-metal content in the vicinity of the mineralised zones than Tephrosia sp. nov. In the case of Eriachne mucronata, this is illustrated by Transect 6, (Fig. 18), where this species is restricted to the lead- and zinc-rich soils of the footwall, while Tephrosia sp. nov. is widespread over the barren hanging-wall shales. Likewise, examination of the distribution of Bulbostylis barbata within the Lode assemblage north of Acacia Creek, (Fig. 13), indicates that it is largely confined to a narrow zone on either side of the Lode, while Tephrosia sp. nov. covers a much more extensive area on the bordering shales. Similarly, comparison of the distribution of Polycarpaea glabra and Tephrosia sp. nov. with the level of copper, lead and zinc in the soils over the mineralised zone, (Figs. 5, 12, 13), shows that the former species is restricted to a much narrower range of ore-metal content than Tephrosia sp. nov.

High concentrations of ore-metal in the soil appear to have a marked effect on the distribution of the tree species as well as those of the lower strata. As previously mentioned, the greater part of the Lode outcrop is devoid of tree cover, (Fig. 3B, and Frontispiece). Comparison of Transects 4 and 8, (Figs. 16, 20), suggests that the absence of trees appears to be related to the higher concentrations of lead and zinc in the soils over the mineralised zone. In the latter transect the level of these metals in the soils overlying the Lode and host shales is relatively low, and there is no break in the tree cover. In Transect 4, however, the soils on the Lode and footwall horizons are extremely rich in lead and zinc, and these zones are devoid of trees.

Although trees are entirely absent from those areas where the soils show a very high degree of enrichment in lead and zinc, (and also copper; see Transect 3, Fig. 15), therefore, examination of the transect data indicates that Eucalyptus terminalis can apparently tolerate higher soil concentrations of these metals than other species. This is illustrated by Transect 7, (Fig. 19), where the widespread species E. argillacea and E. brevifolia tend to go out over the mineralised zone but E. terminalis is not similarly affected. A similar variation in the tree cover is also evident in Transect 9, (Fig. 21), where, moreover, the soils over the sub-outcropping Lode are relatively poor in lead and zinc, and the Lode assemblage, apart from Bulbostylis barbata, is absent. Thus, at this locality, the presence of mineralisation has apparently influenced the distribution of the tree species, while the herbaceous plants are but little affected.

(c). Conclusions

(i). A distinct assemblage comprising the species Tephrosia sp. nov. (Dugald R. MMC/DMJP No. 5), Polycarpaea glabra, Eriachne mucronata, Bulbostylis barbata and Fimbristylis sp. (Dugald R. MMC/DMJP No. 279) replaces the more widespread herbaceous vegetation over outcropping lead-zinc ore deposits within the Dugald River Lode Area. A similar assemblage also occurs over zones of outcropping copper mineralisation, but only where this mineralisation is found in siliceous or argillaceous rocks.

(ii). Trees are generally absent over occurrences of copper or lead-zinc ore. Thus, over the greater part of its outcrop length, the Dugald River Lode and host rocks are devoid of tree cover. With the exception of Eucalyptus terminalis, which can withstand higher concentrations of ore-metal in the soil than other tree species, none show a direct affinity with the mineralised zones.

(iii). The members of the Lode assemblage have a scattered distribution in areas remote from the mineralised zones in the Lode Area. Some of these occurrences mark the site of pockets of low grade copper or zinc mineralisation, or of zones of metal enrichment in the near-surface soils, while others are apparently unrelated to mineralisation.

(iv). Apart from Tephrosia sp. nov., (see below), factors of relief and drainage seem to have little influence on the distribution of the species of the Lode assemblage. Thus the assemblage on the hangingwall shales at the south end of the Lode outcrop, where they form a pronounced ridge, differs little from that occupying the mineralised zone at lower elevations further to the north.

(v). The present-day distribution of Tephrosia sp. nov. is largely confined, in the immediate vicinity of the Lode, to those areas of low elevation and, presumably, more favourable water supply. Thus, factors of relief and drainage appear to exert a considerable influence on the distribution of this species. However, as evidenced by the occurrence of dead stalks and branches on those areas where the Lode shales form a pronounced ridge, this species was formerly much more widespread, both in regions of high and low elevation, along the outcrop of the shale horizon. The reason for its death on the upland regions may lie in the drought conditions which prevailed in the area during the years prior to the present study.

(vi). The residual soils occupied by the Lode assemblage differ little in texture, depth or pH from those on the neighbouring shales, occupied by the background vegetation. Thus, the extent of the Lode assemblage does not appear to be controlled by these factors. Where, however, the zone of lead-zinc mineralisation is masked by alluvial material, there may be a change in the specific make-up of the Lode assemblage, or it may largely die out altogether. In the latter case, however, the course of the sub-outcropping Lode may still be followed by the sporadic occurrence of the species of the Lode assemblage within the background vegetation which replaces it.

(vii). Apart from the ore-metals, only phosphorus shows a significant variation between the soils over the zone of lead-zinc mineralisation, occupied by the Lode assemblage, and those on the neighbouring, un-mineralised shales. Even in the case of this element, however, the maximum value in the samples from the Lode zone is only twice that from un-mineralised areas supporting the normal background vegetation. While the higher phosphorus content, possibly related to the occurrence of primary metallo-phosphate minerals in the Lode, may have some bearing on the distribution of the Lode assemblage, the abrupt change in the vegetation over the mineralised rocks suggests that other factors may be more important.

(viii). While factors of relief, drainage, soil type, pH and the major and trace element content in the soil may have some influence on the distribution and extent of the Lode assemblage, the investigations show that it is the presence of mineralisation, and the consequent anomalous concentrations of ore-metal in the overlying soils, which are the dominant factors. Thus, in those regions where the Lode lies below the present-day ground surface, and the level of lead and zinc in the overlying soil consequently lowered, the Lode assemblage gives way to the background vegetation. On the other hand, the assemblage of Eriachne mucronata, Polycarpaea glabra and Bulbostylis barbata attains its maximum width where the grade of ore in the Lode is highest and the metal anomalies in the overlying soil more pronounced and extensive.

(ix). The transect data indicate that, of the three ore-metals, copper and lead exert a stronger influence than zinc on the distribution of the Lode assemblage. Thus the members of the background vegetation can withstand considerably higher soil zinc concentrations than either lead or copper.

(x). Certain members of the Lode assemblage can apparently withstand higher concentrations of copper, lead and zinc in the soils than others. Eriachne mucronata, Polycarpaea glabra, Bulbostylis barbata and, to a more limited extent, Fimbristylis sp. can all survive on soils extremely rich in these metals. Tephrosia sp. nov., on the other hand, seems unable to do so. At the present day, this species is largely confined to the northern end of the Lode outcrop, where the soils are relatively low in copper, lead and zinc. Even in the past, however, this species seems to have avoided the areas of maximum soil metal enrichment, since no dead stalks or branches were found over those zones.

(xi). On the other hand, within the immediate vicinity of the Lode, Tephrosia sp. nov. is found over a wider range of copper, lead and zinc concentrations in the soil than the other members of the Lode assemblage, which are generally restricted to those areas where the soils show maximum enrichment in these metals.

(xii). Apart from Fimbristylis sp., which appears to show a certain affinity with the zones of copper mineralisation in the hangingwall of the Lode, none of the assemblage species are associated with a certain type of mineralisation, but rather with mineralised areas in general. Where the mineralisation occurs in calcareous host rocks, however, and the overlying soils consequently basic, the species normally associated with mineralisation are generally absent.

(3). The Turkey Creek Area

(a). Introduction

The major features of the Turkey Creek Area were described in the previous section, and only a brief summary will be given here. The area lies some 6½ miles north of the Dugald River Lode, (Fig. 2), and contains several linear belts of malachite-stained micaceous shales. These outcrop over a width of some 200 ft. and length of over 1000 ft. in the western part of the area. They are marked by a distinct assemblage of Tephrosia sp. nov., Polycarpaea glabra, Eriachne mucronata and, to a lesser extent, Bulbostylis barbata, (Fig. 10B).

The micaceous shales occur within an extensive zone of micaceous and calcareous calc-silicate rocks. The latter type weathers more easily than the micaceous variety, and thus is generally found on lower ground. Massive quartzite, apparently associated with a shear zone, forms high country in the north-east. Similar material outcrops in low ridges throughout the remainder of the region.

The area is traversed by a number of deeply-incised creeks, generally of a small size, which flow north and west to join Cabbage Tree Creek. Erosion is relatively severe, and soils are shallow and gravelly over the greater part of the area. In the south-west, however, Arid Red Earth soils have developed on sheet wash alluvium derived from higher ground to the south.

(b). <u>The distribution of the species associated with mineralisation</u>

With the exception of <u>Fimbristylis</u> sp., all the species associated with the lead-zinc deposit in the Lode Area occur at Turkey Creek. <u>Polycarpaea glabra</u>, and <u>Eriachne mucronata</u> form a well-defined assemblage over the zones of maximum copper staining, (Fig. 10B). <u>Bulbostylis barbata</u>, though less abundant, is common in these areas also, but in addition is found sparingly on un-mineralised rocks in the south-central part of the region. Slightly to the north and west of this locality, <u>Eriachne mucronata</u>, with Tephrosia sp. nov., is associated with an isolated zone of malachite-staining.

The distribution of this latter species is particularly interesting. As indicated in Plate 18, the plant is absent over the zones of high copper enrichment, (occupied by Polycarpaea glabra), but occurs as a bordering zone on the more weakly-mineralised shales on either side. This possibly suggests that Tephrosia sp. nov., while tolerant of copper in the rooting medium, cannot withstand excessive amounts. It will be recalled that the species showed a similar avoidance of areas with very high soil lead and zinc contents in the vicinity of the Lode.

The shrub is also common, though only as dead stalks and branches, to the east of the main zones of malachite-stained rocks. Here it occurs on micaceous calc-silicates and quartzite. Where the calc-silicates are of the calcareous variety, however, as along the larger creek draining the eastern half of the area, then the species is rare or absent entirely. This bears out the observation made in the discussion of the Lode Area, that this species tends to avoid basic soils. It is of interest to note that the distribution of Tephrosia sp. nov. in the eastern part of the Turkey Creek Area shows a fairly close correlation with that of Eucalyptus brevifolia. As described in Section B, this species is also rare on basic soils.

Plate 20 *Polycarpaea glabra* on copper-bearing shales at the Bedford Mine

Plate 21 *Eriachne mucronata* on copper-bearing schists south-east of Turkey Creek

Plate 20 *Polycarpaea glabra* on copper-bearing shales at the Bedford Mine

Plate 21 *Eriachne mucronata* on copper-bearing schists south-east of Turkey Creek

(c). Factors influencing the distribution of the species

A more detailed picture of the variations in the vegetative cover over the mineralised zones in the Turkey Creek Area is provided by Transect 13, (Fig. 23), which crosses several belts of malachite-staining and gossan in the north-west corner.

It is evident that the occurrences of *Polycarpaea glabra* and *Eriachne mucronata* show a striking correlation with the copper-rich rocks. On the other hand, *Cleome viscosa* and *Triodia pungens*, the dominant members of the background vegetation in this region, show a corresponding decrease or absence over these zones. *Tephrosia* sp. nov. is abundant, both as living and dead material, on the shale horizon. The histograms confirm, however, that this species is absent over the zones of maximum copper enrichment, which are occupied by *Polycarpaea glabra* and *Eriachne mucronata*.

The belts of malachite-stained shales do not give rise to any marked topographic feature, and hence the influence of relief on the distribution of plants in this zone can be discounted. Although soils have not been indicated on the diagram, these show little variation in texture or depth throughout the area underlain by shales. Generally they consist of a shallow depth of loose gravelly material. The lack of variation between the soil of the mineralised and un-mineralised shales indicates that soil drainage

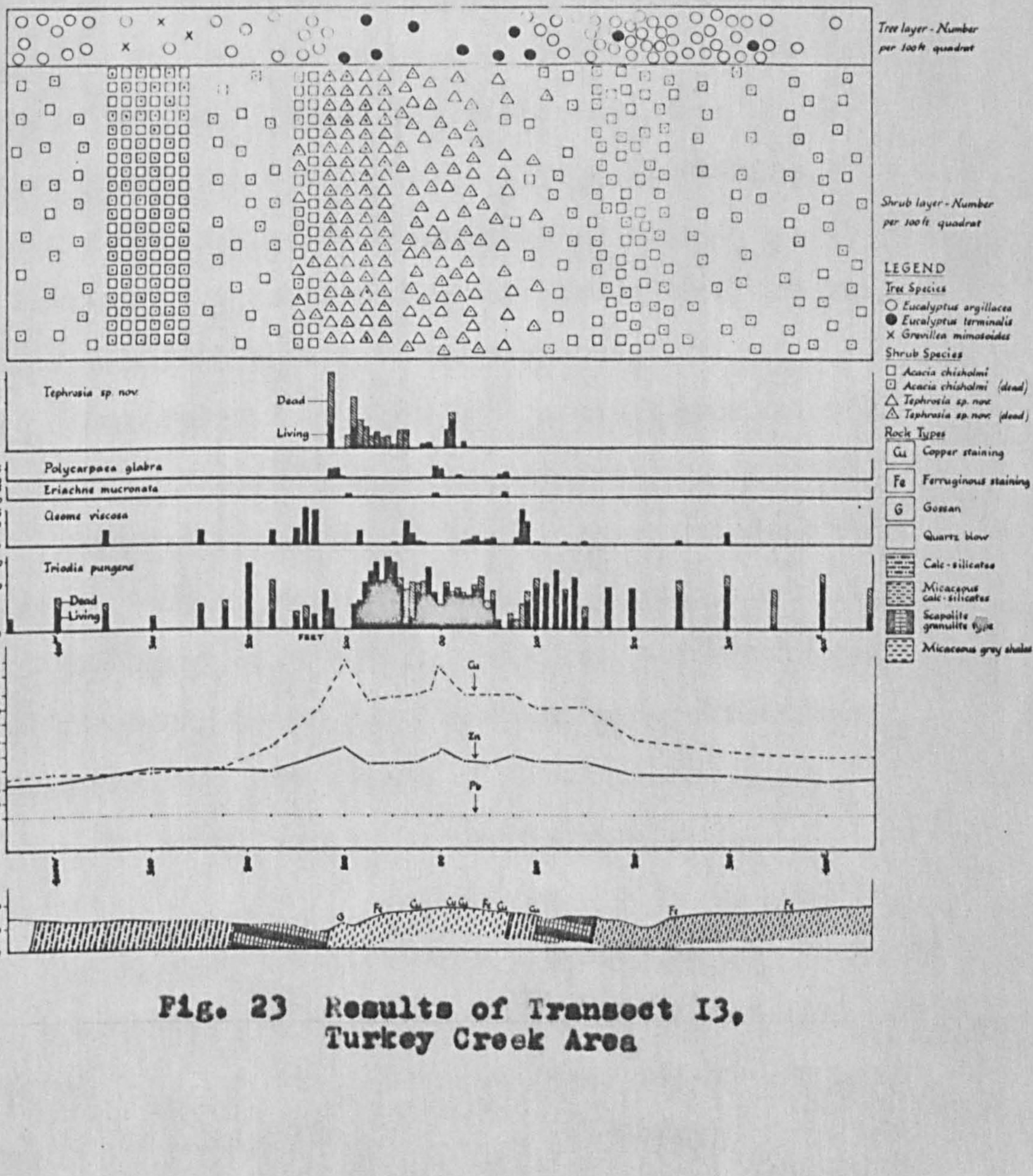


Fig. 23 Results of Transect I3, Turkey Creek Area

has no strong bearing on the occurrence of the assemblage species.

Although the pH of the soil has an apparent influence on the distribution of Tephrosia sp. nov., (thus it is absent over the calcareous calc-silicates bordering the shale horizon), there is little variation in the soil pH throughout the latter unit. Two soil samples from the zone of malachite-staining gave pH values of 5.7 and 5.8, (Table 4). These are slightly lower than the range found in soils from un-mineralised shales, (pH 6.0 to 6.4), but it seems improbable that such a small variation can have led to the marked change in the vegetative cover.

Table 4 indicates, however, that the phosphorus values in the samples from the zones of copper mineralisation are comparatively high. A similar enrichment was apparent in the soils overlying lead-zinc mineralisation. It is possible that the source of the phosphorus in these areas lies in primary metallo-phosphate minerals, such as, in the case of copper, libethenite, ($4\ Cu\ P_2O_5\ H_2O$). The high concentrations of this element may have a bearing on the distribution of the species associated with mineralisation. In the Lode Area, however, relatively large phosphorus values also occur in soils derived from the shales bordering the Lode, where the assemblage species are absent. This suggests that the element is not the controlling factor in plant distribution over the mineralised zones.

Since the relief, drainage and soils differ little between the belts of malachite-staining and the unmineralised rocks on either side, it would seem that the reason for the marked variation in the vegetation lies in the anomalous concentrations of copper in the substrate. As indicated in Fig. 23, the distribution of <u>Polycarpaea glabra</u> and <u>Eriachne mucronata</u> shows a very close correlation with the peaks of the curve for copper in the near-surface soils. Hence, as in the Lode Area, these species occur over the zones of maximum metal enrichment. On the other hand, <u>Tephrosia</u> sp. nov. avoids these areas, but occurs over soils showing a comparatively wide range of copper contents. Again this agrees with the observation concerning the distribution of this species in the vicinity of lead-zinc mineralisation.

It is apparent that the assemblage species, particularly <u>Polycarpaea glabra</u> and <u>Eriachne mucronata</u>, are capable of withstanding very high concentrations of copper in the rooting medium. Correspondingly, the more widespread species tend to avoid the areas of maximum metal enrichment. This suggests that the reason for the growth of the assemblage species over the zones of malachite-staining lies in a better ability to survive under these conditions than other plants. This point will be further discussed in the following section.

While the change in the vegetative cover is most striking in the herbaceous and shrub strata, the transect data also indicate that there is a variation in the tree canopy. The shale horizon containing the mineralised zones is occupied by a sparse growth of Eucalyptus terminalis, replacing E. argillacea which dominates the tree stratum on the neighbouring un-mineralised rocks. It appears that the former can withstand higher concentrations of copper in the rooting medium than E. argillacea, a suggestion which ties in with their distribution in the vicinity of lead-zinc mineralisation.

Although living specimens of Tephrosia sp. nov. are confined to the environs of the malachite-stained shales in the Turkey Creek Area, the abundant dead stalks on the apparently un-mineralised calc-silicates and quartzites to the east testifies to a former more widespread distribution. No surface indication of mineralisation was evident in these rocks, while reference to Transect 12, (Fig. 11), shows that the overlying soils are low in the ore-metals. It appears, therefore, that the occurrence of the shrub is here unrelated to mineralisation.

The reason for the death of this species in the eastern half of the area but its survival in the vicinity of the malachite-stained shales is unclear. It will be recalled that the present-day distribution of living specimens of Tephrosia sp. nov. along the lead-zinc Lode was largely confined to regions of lower elevation, althoug abundant dead material was found on the higher ground. It was suggested that the death of the shrub in the latter areas was due to a lowering of the water-table, associated with the drought conditions which prevailed in the region during the years prior to the present study.. Variations in relief in the Turkey Creek Area are less pronounced, however, so that this is unlikely to be the reason for the survival of the shrub in the mineralised sectors but not elsewhere. It must be stated that the precise cause of this anomalous distribution of Tephrosia sp. nov. is not known.

(d). Conclusions

(i). The species Polycarpaea glabra, Eriachne mucronata, Tephrosia sp. nov., and to a lesser extent, Bulbostylis barbata, are associated with zones of outcropping malachite-stained shales in the Turkey Creek Area. In these areas the plants form a distinctive assemblage, replacing the more widespread members of the herbaceous and shrub strata.

(ii). Although living specimens of Tephrosia sp. nov. are confined to the mineralised zones, dead stalks and branches also occur over a wide zone of calc-silicates and quartzite to the east. The reason for its survival in the former areas but not in the latter is unclear. The soils derived from the calc-silicates are low in the ore-metals, and hence the shrub is here apparently not associated with mineralisation. Both in this area and in the vicinity of the malachite-stained shales, however, the species is largely absent over calcareous rocks. It would appear, therefore, that it is intolerant of basic soils.

(iii). The belts of copper-stained rocks do not give rise to any marked topographic feature. Likewise, the soil depth, texture and pH is relatively uniform throughout the shale horizon which contains the mineralisation. Thus factors of relief, drainage and soil pH appear to have little influence on plant distribution in this area. High phosphorus contents, possibly derived from metallo-phosphate minerals associated with the copper mineralisation, in the soils overlying the mineralised zones may have a bearing on the marked variation in the vegetative cover. It is more probable, however, that the large concentrations of copper in the rooting medium is the prime factor.

(iv). The displacement of the background vegetation by the assemblage species in the vicinity of the mineralised zones is probably due to the latter group being better adapted to withstand the high soil copper contents. Of the assemblage species, <u>Polycarpaea glabra</u>, <u>Eriachne mucronata</u> and <u>Bulbostylis barbata</u> can apparently survive on soils containing larger quantities of copper than

Tephrosia sp. nov.

(v). Apart from a sparse growth of Eucalyptus terminalis, the mineralised zones and immediate surroundings are devoid of trees. It appears that this species can withstand higher concentrations of copper in the soil than, for example, E. argillacea which is widespread elsewhere in the region.

(4). Isolated occurrences of the species associated with mineralisation

(a). Introduction

The investigations in the Lode and Turkey Creek Areas indicated that distinctive plant assemblages were associated with both lead-zinc and copper mineralisation in the region. The assemblages comprise the species Tephrosia sp. nov., Polycarpaea glabra, Eriachne mucronata, Bulbostylis barbata and Fimbristylis sp. Bulbostylis barbata was only observed in the areas studied in detail, i.e. the Lode and Turkey Creek Areas and the Area north-east of the Quartzite Range, and its distribution has been discussed in the relevant sections. Similarly, Fimbristylis sp. was not found outwith the Lode Area.

Mapping throughout the entire Dugald River Area revealed numerous isolated occurrences of the remaining species normally associated with mineralisation, (Fig. 24). In the majority of cases the plants marked the site of small copper showings. In other localities, however, no obvious indications of mineralisation were present. Several geochemical traverses were made across the latter type of occurrence, with a view to determining whether the plants were associated with anomalous concentrations of ore-metal in the underlying soil. If this were the case, then the presence of the plants in areas remote from mineralisation might be a guide to unsuspected mineralisation at depth. Several samples of the species from these localities were also collected for biogeochemical analysis, (Section D).

(b). <u>The factors influencing the distribution of the species</u>

The distribution of the assemblage species in the Lode Area indicated that the plants avoided those areas where the soils were strongly basic. Thus, few, if any, of the plants normally associated with mineralisation were present where mineralisation occurred in calcareous rocks, e.g. the small copper showings in the limy calc-silicates west of the Lode.

This observation was confirmed by the regional mapping. This indicated that, whether the neighbouring rocks were mineralised or not, the species were almost invariably restricted to soils derived from quartzite, shales, the siliceous variety of calc-silicate, quartzite colluvium or Arid Red Earth Soils.

Although <u>Tephrosia</u> sp. nov. attains its greatest

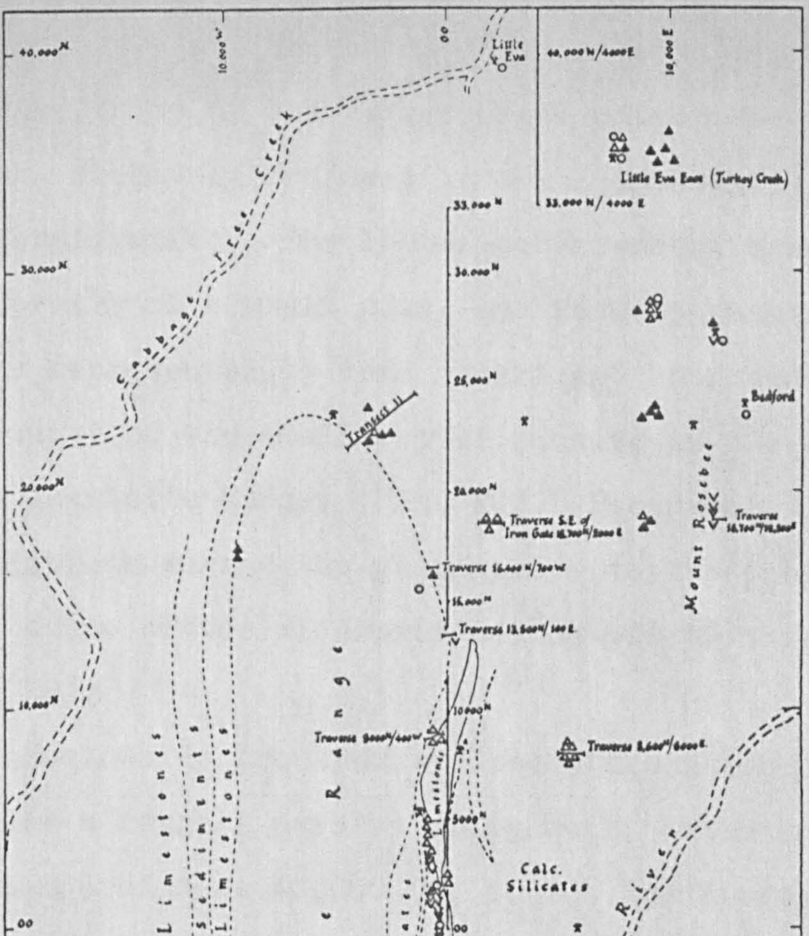
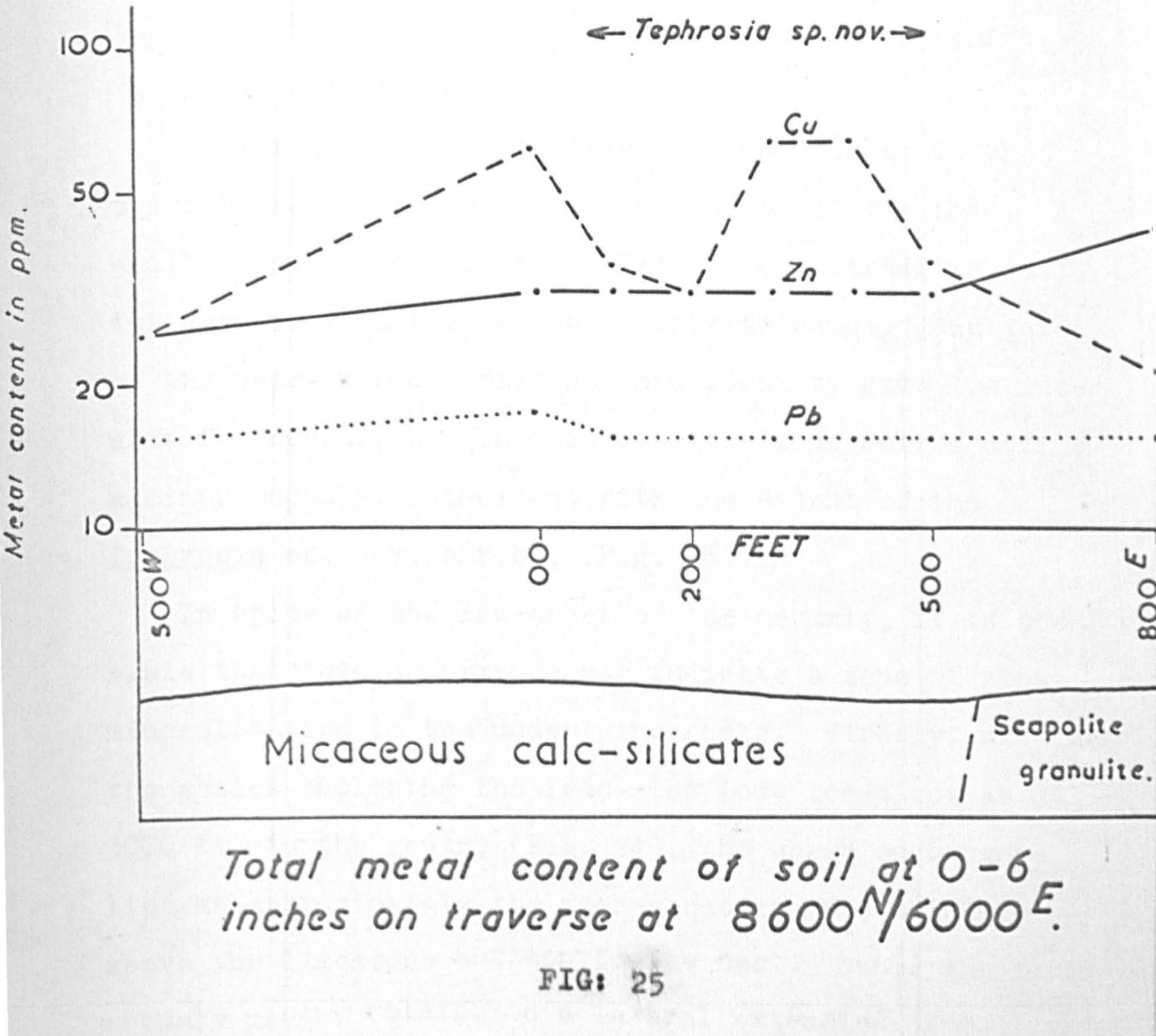


Fig. 24 Distribution of Species Associated with Mineralisation in the Dugald River Area

abundance along the outcrop of the lead-zinc Lode and in the vicinity of the Turkey Creek copper showing, it is also relatively frequent in areas apparently devoid of mineralisation. The latter occurrences, however, are generally of a small size, and in many cases the shrub is only represented by dead stalks and branches, e.g. in the vicinity of the small copper showing on the west side of the Quartzite Range, (Fig. 24). Presumably the drought conditions during the years prior to the present study is the cause of the widespread dying-off of this species, (p. 38).

Southwards from Turkey Creek, the shrub occurrences follow a roughly parallel alignment, extending over a distance of some 40,000 ft. to the Two Sports copper showing east of the Lode. The presence of copper in the southern part of this zone is confirmed by soil and stream sediment analysis, and by malachite staining in some of the calc-silicate outcrops, (Nicolls, 1964). Some of the northern occurrences, in addition to that at Turkey Creek, are also associated with small pockets of malachite-stained shales.

In others, however, no indications of mineralisation were observed. One of these, at 8600N/6000E, (Fig. 24), was made the site of a geochemical traverse. The results, (Fig. 25), show that the residual soils occupied by <u>Tephrosia</u> sp. nov. contain slightly anomalous concentr-



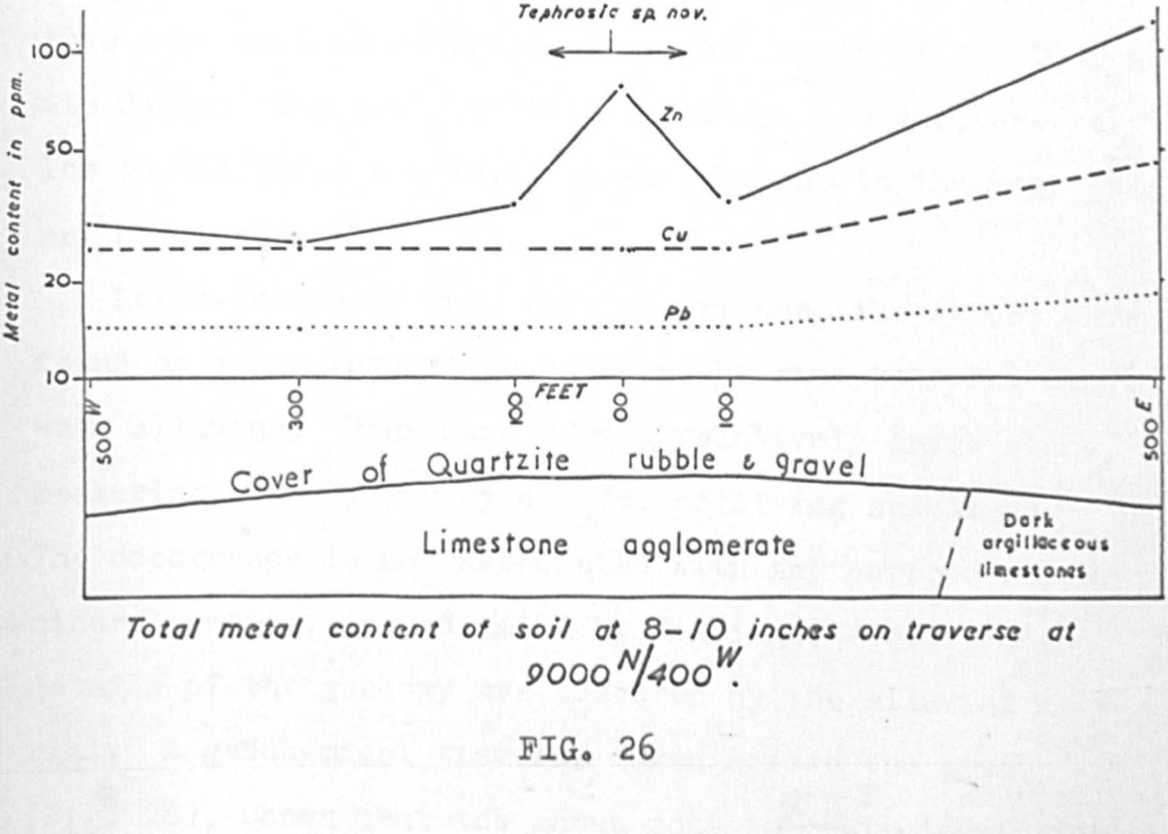
Total metal content of soil at 0-6 inches on traverse at 8600 N/6000 E.

FIG: 25

ations of copper. This may be related to copper mineralisation in the underlying calc-silicates, though it should be noted that the maximum value is barely above the threshold value of 60 ppm for soils, (Table 5). Nevertheless, the close correlation between the extent of the shrub and the metal anomaly is very striking.

A similar north-south alignment is evident in the distribution of the shrubs to the north of the Lode. A small stand was noted at 9000N/400W, on quartzitic colluvium derived from the near-by Quartzite Range. Analysis of the near-surface soils at this locality gave low results for copper, but in this case the zinc values define a minor anomaly, coincident with the extent of the Tephrosia sp. nov. shrubs, (Fig. 26).

In spite of the low order of the anomaly, it is possible that this occurrence may indicate a zone of zinc mineralisation in the underlying rocks. Firstly, although the shales enclosing the lead-zinc Lode lense out about 3000 ft. to the south, (Fig. 24), the shrub occurrence lies at approximately the same stratigraphic thickness above the limestone horizon to the east. Hence the zinc anomaly may be related to a lateral extension of the lead-zinc mineralisation. Secondly, assuming zinc were present in the bedrock at this locality, its dispersion into the near-surface soils would probably be largely inhibited by the overlying quartzite debris. This material is derived



Total metal content of soil at 8–10 inches on traverse at $9000^{N}/400^{W}$.

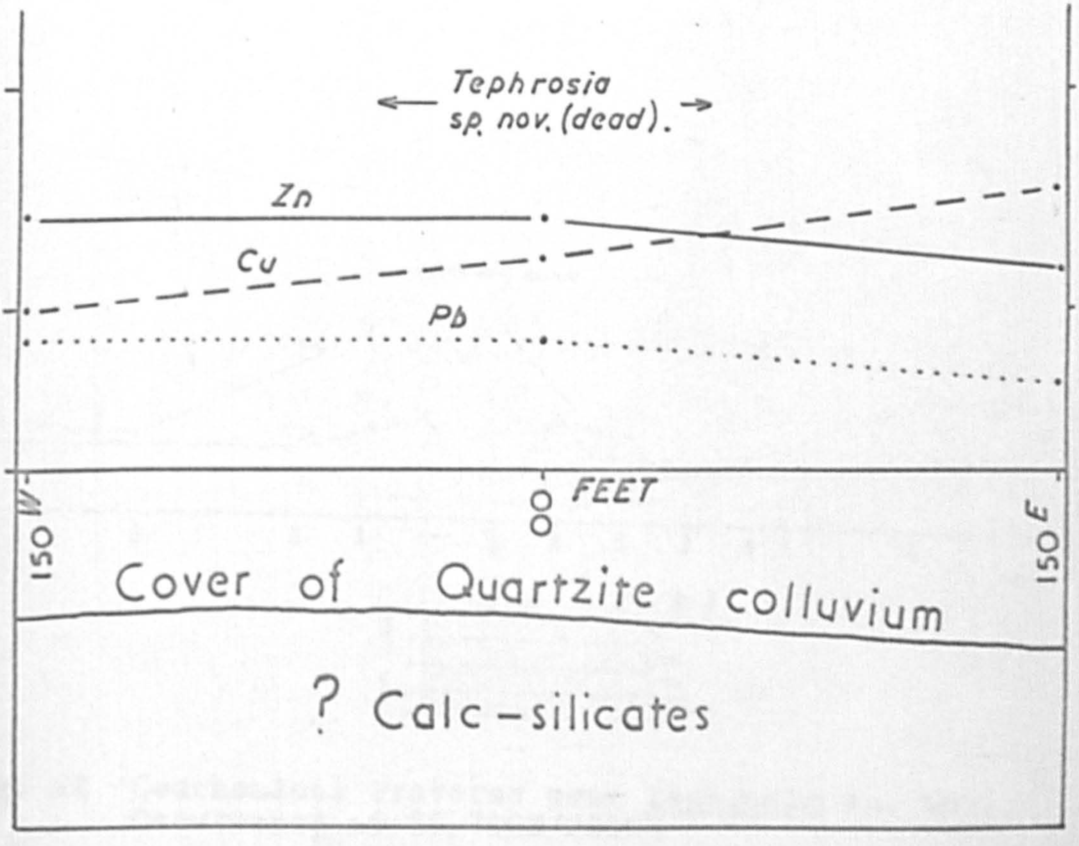
FIG. 26

from the barren Quartzite Range, where zinc mineralisation is unknown. These facts lend an added significance to the zinc anomaly in the soils at this site, and tend to suggest that the source of the metal lies in the bedrock. Deeper sampling, however, would be required to confirm this.

Further north the shrub was again noted, though in this case as dead material, near the margin of the Quartzite Range. The soils at this locality, however, are very low in all three metals, with no increase in the _Tephrosia_ sp. nov. zone, (Fig. 27).

North-eastwards from this occurrence, the shrubs were found on a low interfluve veneered by fine-textured sheet wash alluvium. They here form a relatively large stand, measuring roughly 200 by 400 ft. of living specimens. The occurrence is not associated with any obvious copper mineralisation, as indicated by diggings, etc., though details of the geology are obscured by the alluvial material. A geochemical traverse taken across the area, (Fig. 28), shows that the shrub zone is co-incident with a copper anomaly in the near-surface soils. Minor peaks occur in the curve for zinc, but the values do not exceed the anomaly threshold. Samples from a soil profile near the centre of the stand show an increase from 125 to 225 ppm copper from 0 to 16 ins.

The geochemical results from this locality provide the



Total metal content of soil at 8–10 inches on traverse at 16400N/700W.

FIG. 27

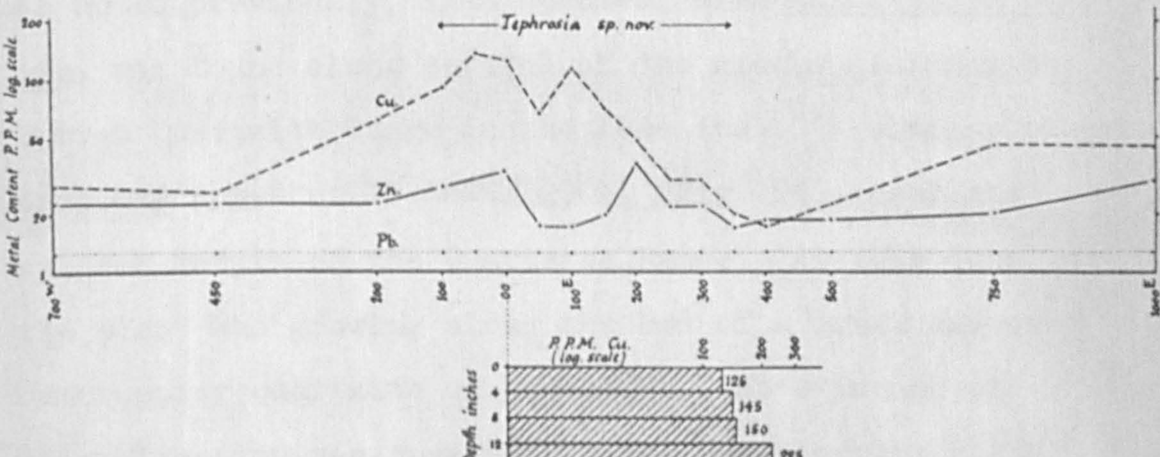


Fig. 28 Geochemical Traverse over _Tephrosia_ sp. nov. Occurrence at 18,700N/2000E

strongest evidence that the distribution of Tephrosia sp. nov., in regions where no obvious indication of mineralisation exists, may be related to unsuspected ore-deposits at depth. Again, however, further investigations, including geochemical sampling to the bedrock, is required before definite conclusions may be drawn.

The perennial herb, Polycarpaea glabra, shows a closer association with regions of outcropping lead-zinc and copper mineralisation than Tephrosia sp. nov. However, as noted previously, this species, with Bulbostylis barbata, was found along several of the creeks draining the barren Quartzite Range in the Lode Area. A similar occurrence was noted at 15,600N/1200W, (Fig. 24), near the eastern margin of the Quartzite Range. At this locality the plant was growing along the bed of a creek and over outcropping quartzite on the banks. No evidence of mineralisation was observed in the neighbouring rocks, while analyses of the stream sediments and soils in which the plant was rooted indicated low values for copper, lead and zinc, (maxima of 38, 10, and 35 ppm respectively).

Apart from these occurrences, the distribution of the species outwith the main centres of mineralisation is confined to isolated copper showings. It was noted on the malachite-stained calc-silicates at the Lady Clare Mine in the south, and on similar rocks at Little Eva in the north, (Fig. 24). South and east of Turkey Creek the herb

Plate 18 *Polycarpaea glabra*, with *Tephrosia* sp. nov. on copper-bearing shales in the Turkey Creek Area

Plate 19 *Polycarpaea glabra*

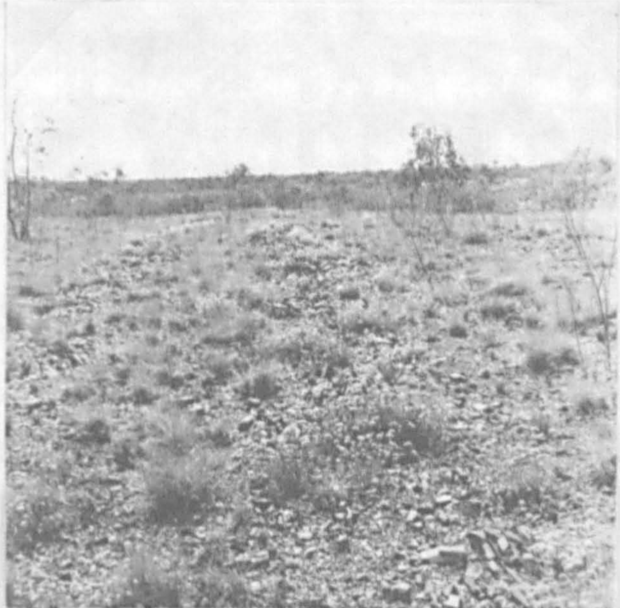


Plate 18 *Polycarpaea glabra*, with *Tephrosia* sp. nov. on copper-bearing shales in the Turkey Creek Area

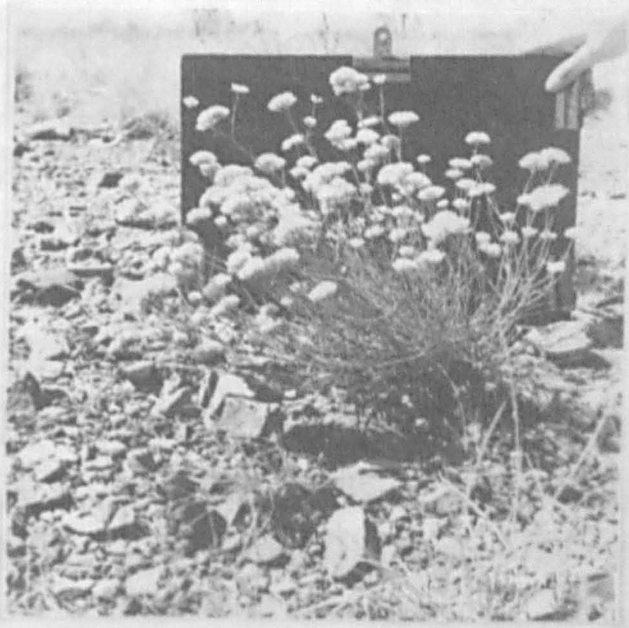


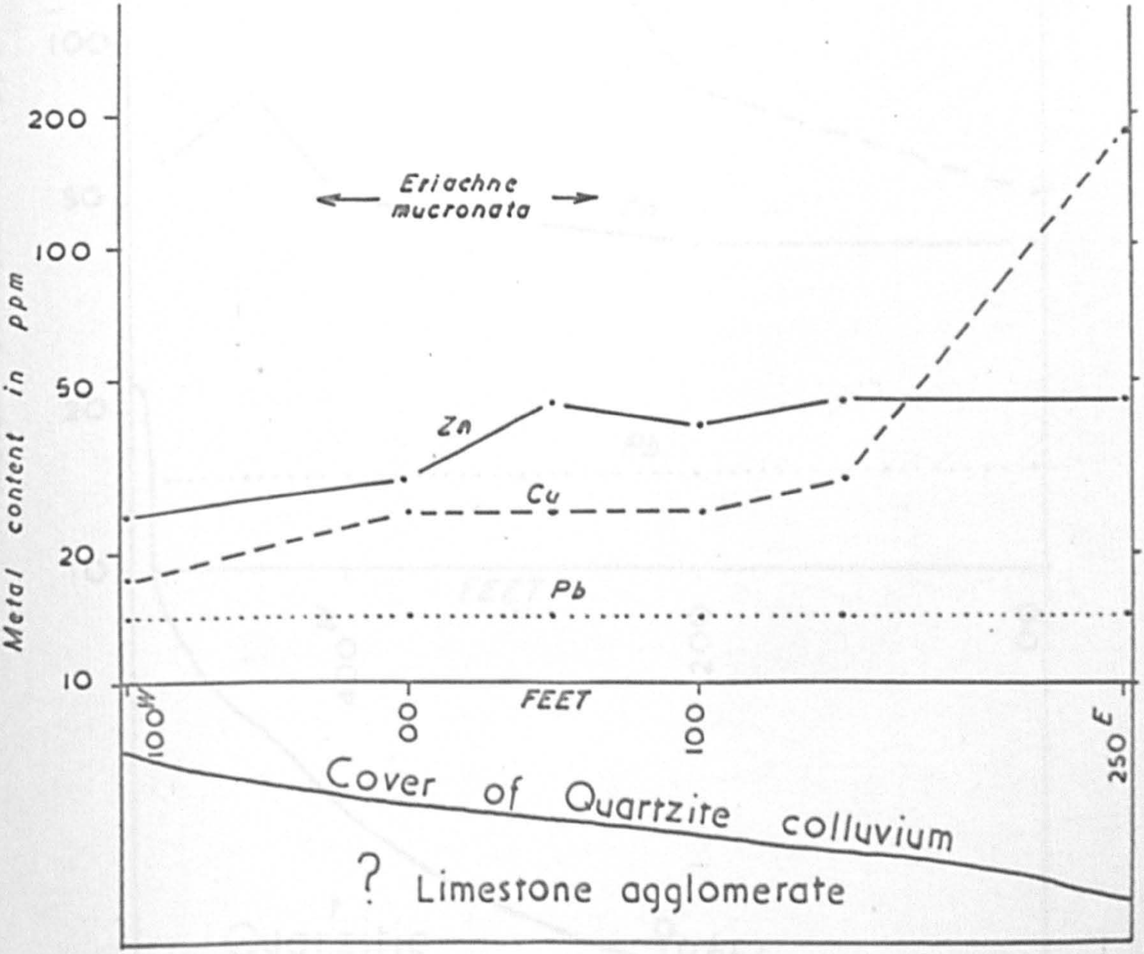
Plate 19 *Polycarpaea glabra*

occurs on several bands of malachite-stained biotite schists, as at the Bedford Mine, (Plate 20).

The light-coloured grass, Eriachne mucronata, lends a distinctive appearance to the vegetation over the Dugald River Lode. It also occurs, though to a lesser extent, on the malachite-stained shales of Turkey Creek, but forms a broad zone over similar rocks some 8000 ft. to the south-east, (Plate 21).

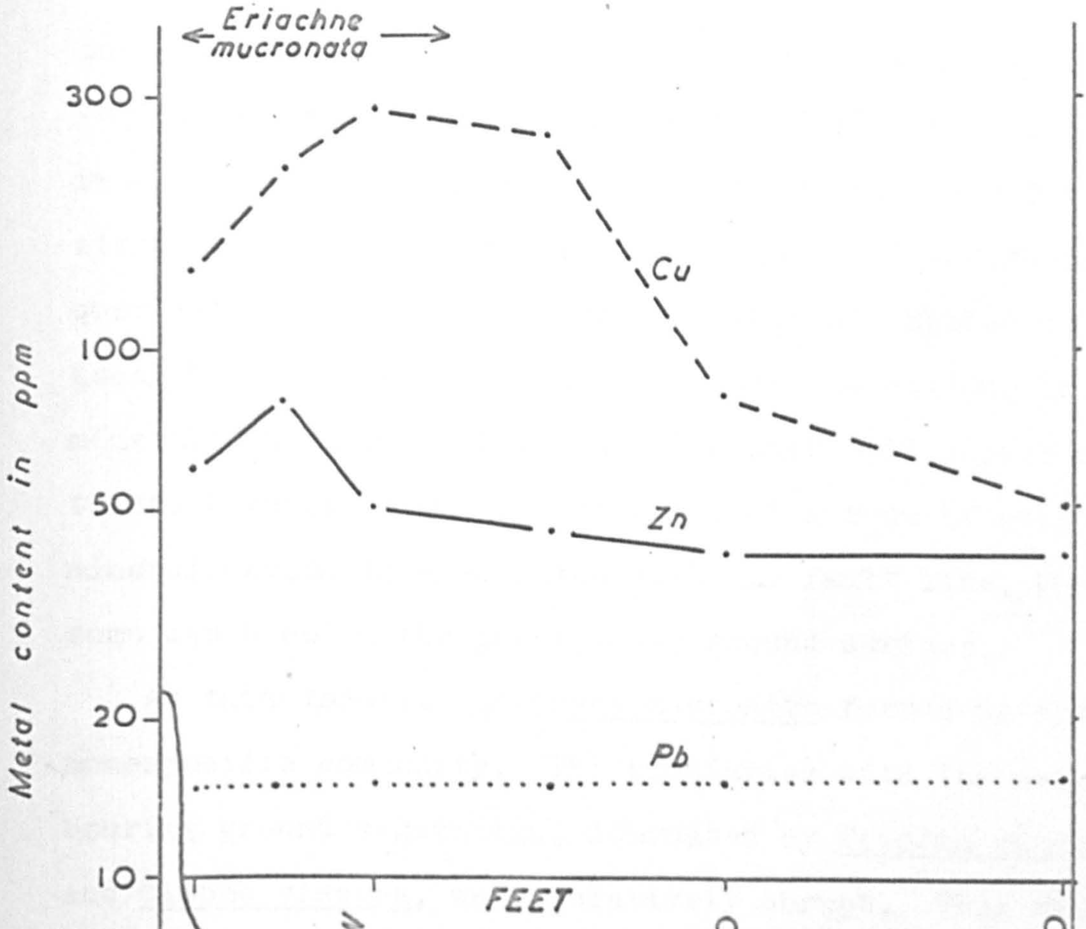
The species is also fairly common in areas where no obvious indication of mineralisation exists, but in these areas its distribution is generally sparse and it rarely forms distinctive communities as over the ore-deposits. A small patch of the grass was observed on quartzite colluvium near the eastern margin of the Quartzite Range at 13,500N/100E. Geochemical analysis of the near-surface soils indicates that zinc shows a small increase in the zone occupied by the grass, but the maximum value is below the anomaly threshold, (Fig. 29). Copper and lead are low in the soils underlying the Eriachne mucronata occurrence, but the level of the former metal rises sharply at the eastern end of the traverse. At this point, however, the cover of quartzite colluvium had decreased in thickness, and the relatively high soil copper content is presumably related to a minor zone of mineralisation in the underlying limestone agglomerate.

A more extensive occurrence was found at the foot of



Total metal content of soil at 6-8 inches on traverse at 13500^{N}/100^{E}.

FIG. 29



Total metal content of soil at 0-6 inches on traverse at 18700N/12200E.

FIG. 30

the steep scarp formed by the Mt. Rosebee fault zone at 18,700N/12,200E. Here both copper and zinc are present in anomalous amounts in the underlying soil, the former attaining a level of 300 ppm, (Fig. 30). Although the quartzitic rock of the shear zone is well exposed at this locality, no malachite stains or other indications of mineralisation were observed. The high soil copper contents, however, strongly suggest that a zone of copper mineralisation is associated with the fault line, but at some depth below the present-day ground surface.

At this locality Eriachne mucronata formed an almost monospecific community. The boundaries with the neighbouring ground vegetation, dominated by Triodia pungens and Cleome viscosa, were relatively abrupt. Thus where the grass forms a well-defined assemblage, and particularly where the assemblage is elongated in the direction of the strike of the geology, the present evidence suggests that the occurrence of the grass is related to a zone of metal-enrichment in the underlying soils. This in its turn may be associated with mineralisation at depth. Where the grass is found as a sub-dominant in the "normal" ground stratum in apparently unmineralised areas, however, the probability of it being associated with metal-enrichment in the underlying soil or bedrock seems less likely.

(c). Conclusions

(i). The pattern of distribution indicated by the species associated with mineralisation throughout the Dugald River Area, confirms the observation made in the Lode Area that the plants generally avoid basic soils.

(ii). All of the species occurred in regions where no surface indication of mineralisation was present. Geochemical analysis of the near-surface soils of several of these occurrences shows that, in the majority of cases, the plants are apparently associated with minor zones of copper or zinc enrichment. Polycarpaea glabra forms an exception to this generalisation, however, (iv).

(iii). In addition to the occurrences in the main areas of mineralisation, Tephrosia sp. nov. is relatively common in the vicinity of small copper showings in the calc-silicate and shale horizons. It is also found, though to a lesser extent, in areas where no obvious mineralisation is present. In these areas it may define the site of minor copper and zinc anomalies in the underlying soil. These occurrences lie in two main zones which follow a roughly parallel alignment. One of these may define a zone of erratic copper mineralisation, extending southwards from the Turkey Creek copper occurrence for a distance of some eight miles. The second possibly indicates a lateral extension of the lead-zinc Lode northwards, and also some scattered pockets of copper mineralisation.

(iv). The distribution of Polycarpaea glabra is largely confined to the main mineralised areas and to smaller zones of malachite-stained shales and calc-silicates. At several localities in the Quartzite Range, however, the plant was found growing in soils and stream sediments containing very low amounts of copper, lead and zinc. The neighbouring rocks did not show any surface indication of mineralisation and on this evidence the occurrence of the plant is here unrelated to metal-enrichment in the underlying bedrock.

(v). The occurrences of Eriachne mucronata outwith the Lode and Turkey Creek Areas, and the smaller copper showings, falls into two main types. On the one hand the grass may be found as a sparse member of the vegetation growing in acid soils, such as those derived from quartzites and siliceous calc-silicates. There seems little doubt that in these areas the presence of the grass is not associated with metal-enrichment in the neighbouring soils or bedrock. Where the species forms a distinct community, however, the present evidence suggests that the underlying soil contains anomalous concentrations of copper and possibly zinc. This enrichment may be related to mineralisation at depth, but this requires further investigation.

(5). Assessment of the role of indicator plants in prospecting for base-metals in the Mt.Isa-Cloncurry field

The investigations in the Dugald River Area revealed that the species Tephrosia sp. nov., (Dugald R. MMC/DMJP No. 5), Polycarpaea glabra, Eriachne mucronata, Bulbostylis barbata and Fimbristylis sp., (Dugald R. MMC/DMJP No. 279), showed a strong association with regions of lead-zinc and copper mineralisation.

Although it was impossible to visit all the known deposits of these metals in the region, examination of several copper occurrences indicated the presence of one or several of the above species. It is therefore probable that the indicator plants found in the Dugald River Area maintain their characteristic affinity with mineralisation throughout the Mt. Isa-Cloncurry field. In other parts of this region, however, there is always the possibility that these species will be replaced by separate indicator plants.

Of the species mentioned above, Bulbostylis barbata and Fimbristylis sp. have a more restricted distribution within the Dugald River Area. Moreover, their small stature and brownish colour in the dry season lends them a relatively insignificant appearance and detracts from their value as indicator species.

On the other hand, Tephrosia sp. nov. is easily recognisable from a distance of several hundred feet by virtue of its height, (Plate 16), and bright green foliage. Even in those areas where the shrub has died off, it is still distinquishable from other species, such as Acacia chisholmi, by its smooth bark and rather slender branches. The value of this species as an indicator of mineralisation is enhanced by the fact that, in these areas, it generally forms relatively large stands. By comparison, the other species are restricted, in the vicinity of the ore-deposits, to a narrower range of soil metal contents.

Although of a smaller stature, <u>Polycarpaea glabra</u> is also visible from a fair distance due to its distinctive white inflorescences, (Plate 19). These persist well into the dry season and therefore, if anything, the plant is more easily recognised at this time of year, when other plants tend to die back. Only two occurrences of this species were observed in barren regions within the Dugald River Area, both in, or on the banks of, creeks draining the Quartzite Range. Otherwise the plant is almost invariably found on zones of outcropping lead-zinc or copper mineralisation. It therefore forms a fairly reliable indicator of base-metal deposits within the region.

<u>Eriachne mucronata</u> is more frequent in areas with no obvious signs of mineralisation than <u>Polycarpaea glabra</u>. At these localities, however, it generally has a rather sparse distribution, and rarely forms distinctive communities. This latter type of occurrence is confined to zones of outcropping mineralisation, or to areas where the soils contain anomalous concentrations of copper or zinc.

This species also has a distinctive appearance. By contrast with the dark green colouration of the almost ubiquitous <u>Triodia pungens</u>, the foliage of <u>Eriachne</u>

mucronata is much lighter in tone. Moreover, during the dry season the grass withers to a light straw colour, while the former species retains its green appearance, (Frontispiece). These factors serve to make the areas occupied by this grass clearly distinquishable from relatively far away.

Although both Tephrosia sp. nov. and Eriachne mucronata are found in areas where mineralisation is not expressed at the surface, the majority of these occurrences mark the site of minor copper or zinc anomalies in the soils. This may be related to mineralisation at depth, though at present this has not been proved for the Dugald River occurrences. In any case, by pinpointing the site of these anomalies, they may narrow the field of search in mineral exploration.

It is of interest that, outwith the areas of outcropping mineralisation, the indicator species almost invariably occur as individuals. One exception to this general rule is the occurrence of Polycarpaea glabra and Bulbostylis barbata along several creeks draining the Quartzite Range. Apart from this example, however, the species never form distinctive assemblages unless mineralisation be present in the underlying bedrock.

Thus the occurrence of one of the indicator species in an area apparently devoid of mineralisation should probably not be considered as absolute evidence of metal-enrichment in the underlying substrate. On the other hand, where several of the plants are found together, the present investigation suggests that mineralisation is almost certainly present in the rocks below. Added to this the distinctive appearance of the indicator plants compared with the more widespread species, and it would seem that they may be of considerable value in geological exploration for copper, lead and zinc in the region.

The distribution of the indicator plants may be useful, not only in reconnaissance prospecting for base-metals, but also in the initial determination of the surface extent of mineralisation. Thus, in the Dugald River Lode Area, the distribution of the Lode assemblage conforms very precisely to the surface expression of both the Main and West Lodes, and also defines the malachite-stained shales which occur in the hangingwall at several localities. Moreover, where the Lode lenses out on the surface, there is a consequent decrease or absence of the assemblage species. Similarly, at the Turkey Creek copper occurrence, the belts of *Polycarpaea glabra* show a very close correlation with the outcrop of the linear bands of malachite-stained micaceous shales. *Tephrosia* sp. nov. also lends the vegetation over the mineralised rocks in this area a distinctive appearance, and was the initial cause of their discovery.

Variations in the tree cover may also be of importance in prospecting in this region. Eucalyptus terminalis is apparently able to withstand higher soil-metal concentrations than the other widespread trees; hence, a sparse, mono-specific growth of this species may be an indication of mineralisation. More frequently, however, the ore-deposits are entirely devoid of trees or shrubs, (with the exception of Tephrosia sp. nov.), contrasting sharply with the woodland normally found on the neighbouring, unmineralised rocks, (Frontispiece). It should be added, however, that a sparse tree cover is a common feature of the low interfluves occupied by the Arid Red Earth soils and on parts of the flood plains. Thus absence of trees or shrubs may only be used as a possible guide to mineralisation in areas of residual soils.

One important reservation should be made, however, regarding the indicator plant prospecting method. On the evidence available from the Dugald River Area, the indicator plants are confined to acid or neutral soils. Where mineralisation occurs in a calcareous environment, as in the case of the copper showings in the limy calc-silicate rocks, the species only occur sparsely, if at all, in the vicinity. Although the vegetation over this type of copper deposit was investigated thoroughly, no species emerged as an indicator of copper in calcareous host rocks. Certain plants, notably Scaevola densivestita, were common in these localities, but this species was also frequent in other areas of calcareous soil where copper was absent.

Conclusions

(i). Examination of several copper deposits in the Mt. Isa-Cloncurry mineral field indicated the presence of several of the species associated with mineralisation in the Dugald River Area. The distribution of these species, particularly *Tephrosia* sp. nov., *Polycarpaea glabra*, and *Eriachne mucronata*, could probably be used as a guide to lead-zinc and copper mineralisation throughout the region.

(ii). The indicator species have a distinctive appearance, and in all cases are recognisable from a fair distance. *Tephrosia* sp. nov. is distinquishable by its bright green foliage and *Polycarpaea glabra* by its white inflorescences. Likewise, the light straw colour of *Eriachne mucronata* during the dry season makes a sharp contrast with the darker colour of the leaves of the widespread *Triodia pungens*.

(iii). The occurrences of *Tephrosia* sp. nov. and *Eriachne mucronata* in regions not known to be mineralised may mark the site of minor copper and zinc anomalies in the underlying soil. These may be related to mineralisation at depth, but this point requires further investigation. *Polycarpaea glabra* is only rarely found in regions where no surface indication of mineralisation exists, and here is unrelated to anomalous metal contents in the substrate.

(iv). Individual occurrences of the species in areas remote from known ore-deposits may not be associated with mineralisation at depth. Where, however, the indicator plants are found growing together as distinct assemblages, then the present evidence indicates that mineralisation will be present in the underlying bedrock.

(v). The distribution of the indicator plants over the lead-zinc and copper deposits in the study-area shows a close correlation with the outcrop of the mineralised zones. This characteristic could prove useful in the initial determination of the surface extent of an ore-body.

(vi). A sparse stand of Eucalyptus terminalis may be a guide to the occurrence of mineralisation in the rocks below. Apart from this species, most trees avoid the mineralised zones. Hence, an area devoid of trees in the midst of an otherwise well-wooded region could be an indication of an ore-deposit at depth. This only applies to upland areas of residual soils, since areas with a sparse tree cover are relatively common on the low-lying regions with alluvial soils.

(vii). On the evidence available in the Dugald River Area, the indicator plants are intolerant of basic soils. Thus copper mineralisation, when occurring in calcareous host rocks such as the limy calc-silicates, is unlikely to be indicated by the species.

(6). General conclusions on the distribution of the plant species associated with mineralisation

(i). A distinctive plant assemblage, comprising the species *Tephrosia* sp. nov. (Dugald R. MMC/DMJP No. 5), *Polycarpaea glabra*, *Eriachne mucronata*, *Bulbostylis barbata* and, more rarely, *Fimbristylis* sp., (Dugald R. MMC/DMJP No. 279), is found over outcropping lead-zinc and copper mineralisation in the Dugald River Area.

(ii). *Fimbristylis* sp. seems to show a certain affinity for copper mineralisation in the Lode Area, but also occurs sparingly over the lead-zinc deposits. With this exception, there is no essential difference in the specific composition of the assemblage developed over lead-zinc mineralisation and that on copper deposits.

(iii). *Polycarpaea glabra*, *Eriachne mucronata* and *Bulbostylis barbata* can apparently withstand higher concentrations of ore-metal in the substrate than *Tephrosia* sp. nov. Within the mineralised areas, however, this latter species occurs over a wider range of soil metal contents than the other members of the assemblage.

(iv). Factors of relief, drainage, soil texture and soil depth appear to have little influence on the distribution of the assemblage species in the vicinity of mineralisation. The distribution of *Tephrosia* sp. nov. in the Lode Area at the present day, however, is apparently affected by relief and drainage. Living specimens of the plant are largely confined to low-lying country and, presumably, better water supply. The widespread occurrence of dead stalks and branches indicates that the species was once more abundant on higher ground, and hence was formerly more tolerant of a low water supply. The dying-off of this species in the upland areas is probably a result of the drought which affected the region in the years prior to the present study.

(v). High phosphorus contents found in the soils over both copper and lead-zinc deposits may have a bearing on plant distribution in these areas, though relatively high levels of this element also occurred in neighbouring soils where the assemblage species were not present.

(vi). Minor variations in lithology and the acidity of the soil apparently play little part in the distribution of the plant assemblage over the ore-deposits. The assemblage species, however, tend to avoid basic soils, and hence are generally absent from the vicinity of copper showings in the limy calc-silicate rocks of the region.

(vii). It appears that it is not the presence, or absence, of any one element in the substrate which governs the extent of the assemblage in mineralised regions. Rather the occurrence in excess of copper, lead or zinc, seems to form the dominant factor. This is in part borne out by the similarity of the assemblages growing on lead-zinc and copper deposits. The background vegetation seems to be able to withstand higher concentrations of zinc than either copper or lead. Hence zinc may have less influence on the distribution of the vegetation in the vicinity of mineralisation than the latter metals.

(viii). The occurrence of the assemblage species over the mineralised zones probably lies in their better adaptation to the toxic metal concentrations in the soils of these areas than the more widespread plants. The sequence of events was possibly as follows. As the ore-deposits were exposed by erosion, the overlying soils became enriched in the ore-metals. At first these areas were probably devoid of vegetation due to the toxic conditions. Gradually, however, the species now comprising the assemblage developed over these zones became adapted to this environment. Possibly increased competition from other plants played a part in this evolutionary process, and the species migrated to the vicinity of the ore-deposits where the pressure of competition was less severe.

(ix). Several of the occurrences of Tephrosia sp. nov. in areas not known to be mineralised mark the sites of minor copper and zinc anomalies in the underlying soils. The distribution of this species on the apparently largely unmineralised calc-silicates west of the Mt. Rosebee fault zone may indicate a zone of erratic copper mineralisation some eight miles in length. At the northern end of this zone, copper occurs at the Turkey Creek and other showings, while the presence of this metal at the southern extremity has been confirmed by geochemical investigations and traces of malachite-staining. A similar zone of scattered stands of this species may define a northward-extension of the lead-zinc Lode, and possibly also some pockets of copper mineralisation.

(x). An almost monospecific community of Eriachne mucronata on the Mt. Rosebee fault line, where mineralisation is not expressed on the surface, is apparently associated with anomalous concentrations of copper and zinc in the soils. This may be related to an unsuspected ore-body at depth. Where, however, this species occurs as small patches, or where it is found as a subdominant member of the background vegetation, then the present evidence indicates that it is not related to underlying mineralisation.

(xi). The distribution of Polycarpaea glabra in areas devoid of mineralisation is confined to creeks draining the barren Quartzite Range. Here it occurs only sparsely, sometimes with Bulbostylis barbata. Analysis of the stream sediments and bank soils from these areas indicates low values for copper, lead and zinc, and hence the plants are apparently not associated with mineralisation at these sites.

(xii). It would seem that individual occurrences of the assemblage species cannot be taken as absolute evidence of a zone of metal-enrichment in the underlying soil, or of mineralisation at depth. On the other hand, where several of these species are found together, forming a separate assemblage distinct from the neighbouring vegetation, then either lead-zinc or copper mineralisation will probably be present in the bedrock below.

(xiii). The experience gained in the Dugald River Area suggests that the species _Tephrosia_ sp. nov., _Polycarpaea glabra_ and _Eriachne mucronata_ could be utilised as indicator plants in reconnaissance prospecting for copper, lead and zinc throughout the Mt. Isa-Cloncurry field. The plants can be recognised from a fair distance by virtue of their distinctive appearance, especially during the dry season when most field work is carried out. Moreover, the distribution of the species over known ore-deposits may be of value in determining the areal extent of the mineralised zone. As noted in (vi), however, the assemblage species tend to avoid basic soils, and hence are generally absent over copper mineralisation in calcareous host rocks.

SECTION D : BIOGEOCHEMICAL INVESTIGATIONS IN THE DUGALD RIVER AREA

(I). Introduction

As far as can be ascertained from study of the literatu the plant analysis or biogeochemical method has not been previously used in prospecting for base-metals in Australia. The present, preliminary, study was undertaken to assess the possibilities of the method in the Mt. Isa-Cloncurry field. The investigation also sought to provide information on the relationship between the ore-metal content in the plants growing over the mineralised zones and the concentration in the near-surface soil. Such information might, it was felt, give some insight into the factors governing plant distribution in these areas.

A series of leaf samples of the widespread grass, Triodia pungens, was collected from rocks apparently devoid of mineralisation to provide data on the normal or "background" concentration of the ore-metals. Apart from this species, most samples were taken from the plants associated with mineralisation in the area, i.e. Tephrosia sp. nov. (Dugald R. MMC/DMJP No. 5), Polycarpaea glabra, Eriachne mucronata, Bulbostylis barbat and Fimbristylis sp. (Dugald R. MMC/DMJP No. 279).

These species were also sampled when found growing in areas not known to be mineralised. Anomalous metal concentrations in these samples might indicate that the occurrence of the plants was associated with unsuspected mineralisation at depth.

Many investigations, e.g. that by Lotspeich and Markward (1963), have indicated that different parts of the same plant may vary widely in metal content. Where possible, therefore, the plant samples were separated into flowers, fruits, leaves and stems in order to determine which part of the plant showed the most consistent results and would thus be of most value in biogeochemical prospecting.

(a). Role of the ore-metals in plant metabolism and processes involved in their assimilation

Copper and zinc are among the elements classed as micro-nutrients, i.e. they are essential, though in very small amounts, to the proper growth and development of plants. As far as is known, however, no role has yet been observed for lead in plant metabolism.

There seems general agreement that copper plays a role in plant respiration. Hewitt, (1958), found that the enzymes with which copper are associated are all terminal aerobic oxidases which produce water, while Stiles, (1958), lists a number of oxidising enzymes which require copper for their activation.

Zinc has been found in carbonic anhydrase, which catalyses the decomposition of carbonic acid to carbon dioxide and water, (Stiles, ibid). Skoog, (1940), reports that zinc is associated with auxins, while work by Wood and Sibley, (1949), has indicated that between one-fifth and one-half of the zinc present in the leaves of crop plant occurs in the chloroplasts, suggesting that the metal also plays a role in photosynthesis.

Numerous investigators have shown that the uptake of one element by a plant may be influenced by the presence or absence of a second in the rooting medium. Thus Stiles, (ibid), remarks that the adsorption of manganese may be affected by the presence of compounds or iron in the soil. In the experiments of Hewitt, (1953), excess of copper in the rooting medium produced symptoms of iron deficiency, while excess zinc produced apparent manganese deficiency.

The detection of such antagonisms in the present study was complicated by several factors, the most important obviously being that it was made under natural conditions. Thus variations in other soil properties, such as the pH, could affect the uptake of one metal by a plant besides the presence of a second element in the rooting medium.

Secondly, soils rich in zinc were generally relatively high in lead also. Thus comparison was difficult between, for example, zinc-uptake by a plant growing in a high zinc-low lead environment with one from a soil containing high levels of both elements. On the other hand, copper-rich soils were generally poor in lead and zinc, and vice versa. Hence it was rarely possible to compare, for example, copper uptake in a plant from a high copper-low zinc soil with one from a soil containing large concentrations of both

Although the processes involved in the assimilation of the major elements by plants have been the subject of numerous studies, little work has been carried out on the uptake of the micro nutrients. It appears that the first stage in the passage of a metallic ion into the plant is the conversion of the metal to a soluble form in the rooting medium. This occurs by natural weathering processes, perhaps involving conversion to bicarbonates of low or intermediate solubility by the action of carbon dioxide dissolved in rain water. Alternatively, the metal may be rendered into a soluble form by the action of chelating agents produced by microorganisms, (Fritz, 1961).

As yet, there seems no general agreement on the mechanic of the entry of metallic ions into the root, though several theories have been put forward. The Carbon Dioxide Hypothesi proposes that carbon dioxide, released from the root during respiration, reacts with water to produce carbonic acid, which then diffuses to the surface of the soil particles. At this point, exchange takes place between hydrogen ions and adsorbed cations, as a result of which the latter enter ~~s~~ the soil solution and diffuse to the root surface. Here the cation is either absorbed by exchange for hydrogen ions or in association with anions. Although arguments have been raised against this process, Sutcliffe, (1962), considers that it is likely that it plays an important part in the passage of metallic ions into the roots.

A second hypothesis envisages a continuation of the soil solution into the "outer" space of the plant and has be termed Passive Entry. This suggests a concentration functior in which uptake to the shoot is proportional to concentratic and relatively independent of other ions, temperature and metabolic inhibitors, (Fried and Shapiro, 1961). Epstein, (1955), has described experiments demonstrating a passive and reversible permeation of barley roots by sulphate and other inorganic ions through diffusion; The volume so accessible he defined as the outer space of the tissue. The region to which the ions are transported and where they are no longer subject to loss by diffusion or exchange with other ions he defined as the inner space.

It is generally acknowledged that once inside the root, the nutrients are carried upwards in the transpiration stream through the xylem. Thus in the experiments of Stout and Hoagland, (1939), the xylem and phloem of the stems of several plant species were separated by the insertion of strips of waxed paper, though the longitudinal continuity of each element was left intact. Radioactive nutrient elements were then placed in the root environment and the path of the elements traced; at the point of divergence, most, if not all, of the elements moved upwards in the xylen

Biddulph, (1953), remarks that the fate of the minerals swept upwards by the transpiration stream might vary accordi to the element, the plant and the conditions existing within the plant at the time of absorption. He enumerates several possibilities:

1. A portion of the material will be captured by the cells adjacent to the xylem.
2. A portion may move laterally to actively metabolizing cel
3. A portion may move directly to the apical primordia and adjacent regions of active metabolism.
4. A portion may be deposited in the leaves having moved there via the transpiration stream.

(b). Previous work

The studies by Webb and Millman, (1951), and Debnam, (1955), have been reviewed in the Introduction to this report. These appear to be the sole investigations into the biogeochemical prospecting method in tropical climates.

References in the literature to their use in temperate regions are more extensive, however. One of the first investigations was that by the Swedish Prospecting Company, (1939), who showed that a close association existed between the metal content of vegetation and sub-outcropping vanadium tin and tungsten deposits in Sweden and Cornwall.

In Finland, Marmo, (1953), analysed the copper, nickel, zinc and molybdenum contents in the leaves of Vaccinium vitis idaea growing over known copper, zinc and molybdenum mineralisation. This author found that, while even small amounts of these elements in the bedrock were reflected in the plants, biogeochemical methods were most suitable as an adjunct to geophysical techniques. In the same country, Salmi, (I956), made a comparative study of the copper, lead and zinc contents in <u>Ledum palustre</u> and in the underlying peat in an area of lead-zinc mineralisation. There was a I00-fold difference between the highest and lowest copper values in the peat samples, but only a 3 and 5-fold difference respectively for the leaves and twigs of <u>L. palustre</u>. Similarly for zinc the corresponding differences for peat, leaf and twig samples were 30, 30 and 20-fold respectively, and for lead I00, 20 and 20-fold.

Numerous investigations of the biogeochemical method have been carried out by Warren and his co-workers in British Columbia, (Warren, I962, and references in this paper). Particular attention has been given to the tree species, since it was felt that these were more likely to "tap" ore-bodies at depth. After many thousands of analyses, the background values for the elements copper, lead, zinc and manganese have been calculated for the common tree species occurring within the region. Their studies have also shown which part of the tree - second year twigs - gave the most consistent results.

Lovering, Huff and Almond, (I950), analysed a variety of plant species, mostly herbs and grasses, growing over a copper deposit in Arizona. Their results indicated that the level of copper in the plants was relatively low compared with its concentration in the underlying soil. This was considered to be due to the alkalinity of the soil, and the resultant immobility of copper, under the desert climate pertaining in the study-area. They therefore concluded that, under similar conditions, the biogeochemical method offered little advantage over direct analysis of the soil.

The search for uranium in the United States during the past decade has led to many investigations in the Colorado Plateau area, (Cannon, 1960, Kleinhampl, 1962 and Kleinhampl and Koteff, 1960). Both indicator plant and biogeochemical methods have shown fair success in the location of uranium deposits. Thus, in one district, plant analyses found 110 localities which were probably mineralised, and at least 55 of these were considered to contain mineable quantities of uranium.

The biogeochemical methods have been used in Russia for a number of years, and are probably more popular here than in any other country. Tkalich, (1953), reports that the iron content in plants can be utilised in prospecting, not only for deposits of this metal, but also for other sulphide-rich ore bodies. By determination of the iron content in birch and pine leaves in an area of copper mineralisation, it was possible to outline the boundaries of the sub-outcropping deposits. Poskotin and Lyubimova, (1963), also report favourably on the biogeochemical method, as applied to an area in the Middle Urals. Birch and pine trees were again sampled, and it was found that analysis of the leaves and twigs could detect unsuspected lead and zinc mineralisation at depths of up to 30 m.

From the literature reviewed, it will be evident that, whereas some investigations have shown disappointing results, most authors consider that biogeochemical methods may show useful results in prospecting for ore-deposits, including those of copper, lead and zinc with which the present study is concerned. The method would appear to be particularly useful in locating mineralised zones in areas where the bedrock is largely masked by overburden and where the metals are not rendered immobile by alkaline soils.

(c). <u>Analytical methods and presentation of results</u>

Details of the collection, ashing and analysis of the plant samples are given Appendix B and the following is only a brief summary.

(i) After collection and air-drying the samples, where possible, were separated out into flowers, leaves, stems etc. Duplicate samples were ashed using "wet" and dry ashing methods. For the reasons given in the Appendix however, the latter method was thought preferable and all the results shown in the following Tables are based on results obtained from dry-ashed samples. After duplicate analyses on samples of milled and un-milled material, it was apparent that little advantage was gained from milling the samples, and again all the results are based on un-milled material.

The analyses for copper, lead and zinc content of the samples were carried out using a bisulphate fusion and a leach of 1.0 M-hydrochloric acid which is later diluted to 0.5 M. Aliquots of this solution were tested colorimetrically for the above metals.

(ii) The results in all cases are expressed in parts per million of the ash, followed by the values in ppm of the oven-dry material, (in parenthesis).

(iii) In the case of the lead results, the lower limit of detection with the 0.1 gm. sample of ash normally used in the analyses was generally 10 ppm. This is indicated by the sign $<$ preceding the figure. Values greater than 10 ppm and preceded by this sign in the Tables indicates that the lead content was at the lower limit of detection with the sample weight used. This applies particularly to analyses performed on material such as flowers and fruit, where a low sample weight was often necessitated owing to the difficulty of collecting sufficient material to give a weight of ash of 0.1 gm.

(iv) The accuracies and ranges for the analyses of the elements under discussion are as follows:

Copper; Plus or minus 25 % at the 95 % confidence level over the Range of 5 - 20,000 ppm.

Lead; Plus or minus 25 % at the 95 % confidence level over the Range of 10 - 7000 ppm.

Zinc; Plus or minus 25 % at the 95 % confidence level over the Range 5 - 3500 ppm.

(v) Many of the samples contained zinc contents above the top limit of the Range quoted above, and dilution of the sample solution was required. Above the 3500 ppm level, therefore, results outside the 25 % accuracy limits may occur; where possible, duplicate analyses were run to check the results.

(vi) Unless otherwise stated, the soil sampling depth was 4 to 6 ins., and the analyses were performed on the minus 80 mesh material.

(2) Results

(a) Background and threshold values

The background value, or normal abundance of an element in plants growing in un-mineralised areas, will depend on a number of variables. These include the abundance of the element in the underlying soils and rocks, the acididity of the soil, and the age, life-form and species of plant sampled. Similarly, the upper limit of normal background fluctuation, or threshold value, (Hawkes and Webb, 1962), can be expected to vary from area to area and from plant to plant.

The background and threshold levels for copper, lead and zinc in the Dugald River Area were calculated from I6 samples of the leaves of Triodia pungens. The choice of this species was based on its abundance and wide distribution throughout the area. Since the species was sterile at the time of collection, only the leaves were available for sampling.

The samples were collected at the same localities as the soils from the Mt. Isa-Cloncurry traverse, used in the calculation of the threshold values for soils (Table 5). The traverse ran at right angles to the strike of the country rock, which comprises similar rocks to those outcropping in the Dugald River Area, and belong to the same Corella Formation.

The full results of the analyses are indicated in Table 7, and the calculated background and threshold values in Table 8. The lead results remain at the lower limit of detection throughout the length of the traverse; thus a figure of 20 (2) ppm was taken as threshold. Inspection of the results from anomalous areas indicates that lead values above this level were generally significant in defining anomalies.

To facilitate discussion in the following pages, the threshold value for copper has been taken as 70 (4) ppm, and that for zinc as 220 (I3) ppm.

Table 7 : Triodia pungens. Analyses of Plant Samples collected along Traverse following Mount Isa/Cloncurry Road. Un-milled, dry-ashed material.

No.	Locality. Distance in miles W. from Cloncurry	Part of Plant	% Ash	ppm of Ash			Cu/Zn Ratio	ppm of oven-dry material			ppm of soil (4 - 6 ins)			Cu/Zn Ratio	Rock Type
				Cu	Pb	Zn		Cu	Pb	Zn	Cu	Pb	Zn		
30/8282	33	Leaves	5.20	45	<5	120	0.37	2.34	<1	6,24	55	<5	35	1.57	Siliceous sediments
30/8284	32	"	6.27	55	<20	100	0.55	3.44	<1,25	6,27	87.5	<5	20	4,37	Calc-silicates
30/8285	31.5	"	4.68	35	<10	120	0.29	1,63	<1	5.61	82.5	<5	25	3,3	Dark siliceous sediments
30/8291	28.5	"	5.68	60	<10	90	0.66	3.41	<1	5.11	55	<5	20	2,25	Siliceous agglomerate
30/8292	28	"	3.55	62	<5	155	0,40	2,20	<1	5.50	70	<5	25	2,8	Agglomerate
30/8293	27.5	"	4.32	33	<10	70	0,47	1,42	<1	3.02	40	<5	25	1.6	Siliceous agglomerate
30/8295	26.5	"	4.55	45	<10	70	0,64	2,05	<1	3.18	90	<5	35	2.57	Quartzite
30/8302	23	"	5,64	60	<10	220	0.27	3,38	<1	12.40	95	<5	20	4.75	Siliceous sediments
30/8303	22.5	"	3.98	50	<10	60	0,83	1.99	<1	2,38	37.5	<5	20	1.87	Agglomerate
30/8304	22	"	4.31	30	<5	60	0.50	1,29	<1	2.59	22.5	<5	15	1.5	Siliceous agglomerate

No.	Locality Distance in miles W. from Cloncurry	Part of Plant	% Ash	ppm of Ash Cu	Pb	Zn	Cu/Zn Ratio	ppm of oven-dry material Cu	Pb	Zn	ppm of soil (4 - 6 ins) Cu	Pb	Zn	Cu/Zn Ratio	Rock Type
30/8307	20.5	Leaves	6.26	33	< 7	160	0.21	2,06	1	10.02	10	< 5	15	0.66	Calc-silicates
30/8308	20	"	5.73	43	< 7	150	0.29	2,46	< 1	8,59	55	< 5	30	1.83	Calc-silicates
30/8309	19.5	"	5.82	32	< 7	170	0.19	1,86	< 1	9.89	35	< 5	25	1.4	Dark shales
30/8314	17	"	8.42	35	< 7	40	0.87	2,95	< 1	3.37	15	< 5	20	0.75	Siliceous agglomerate
30/8315	16.5	"	8.23	40	< 7	145	0.27	3.29	< 1	11,93	40	< 5	15	2.66	Banded sediments
30/8316	16	"	4.62	45	< 10	180	0.25	2,08	< 1	8,32	10	< 5	15	0.75	Siliceous sediments

Table 8: Calculated Background and Threshold Values in Plants for Copper, Lead and Zinc

	ppm of ash			Cu/Zn Ratio	ppm of oven-dry material		
	Cu	Pb	Zn		Cu	Pb	Zn
Mean	44	<10	119.3	0.44	2.42	<1	6.52
Standard Deviation	13.6	-	51.7	0.21	0.71	-	3.31
Threshold	71.2	20	222	-	3.84	2	13.14

(b) Biogeochemistry of Triodia pungens

As described above, the results of analysis of the leaves of this species from the Mt. Isa-Cloncurry traverse were used to calculate the background and threshold values in plant material. A further group of samples from unmineralised localities in the Dugald River Area were analysed to indicate whether any significant variation occurred in the normal plant metal contents. This species was also samples from the vicinity of lead-zinc and copper mineralisation, forming a basis for comparison with the analyses of the species associated with mineralisation. As in the Mt. Isa-Cloncurry samples, only the leaves were sampled.

The results from background areas at the Dugald River are indicated in Table 9. Both the copper and lead contents are of the same order as those in the samples from the background traverse, (Table 7), but zinc exceeds

Table 9 : <u>Triodia pungens</u>. Analyses of Plant Samples from Background Areas, Dugald River. Un-milled, dry-ashed material.

No	Locality	Part of Plant	% Ash	ppm of Ash			Cu/Zn Ratio	ppm of oven-dry material			ppm of soil (4 - 6 ins)			Cu/Zn Ratio	Rock Type
				Cu	Pb	Zn		Cu	Pb	Zn	Cu	Pb	Zn		
40/161	$55000^S/3000^E$	Leaves	5.05	45	<10	370	0.12	2.27	<1	18.68					Fine alluvium
40/159	$17600^S/4200^W$	Leaves	7.41	45	<10	220	0.20	3.33	<1	16.30					Quartzite rubble on fragmental calc-silicates
40/158	$13700^S/2700^W$	Leaves	5.31	50	<10	160	0.31	2.65	<1	8.49					Quartzite rubble.
40/157	$4400^S/3000^W$	Leaves	6.37	30	<10	50	0.60	1.91	<1	3.18					Quartzite rubble on fragmental calc-silicates
40/155	$2100^S/2100^W$	Leaves	8.08	35	<10	80	0.44	2.82	<1	6.46	10	<25	20	0.50	Quartzite rubble on calc-silicates
40/148	$6650^N/2100^W$	Leaves	5.75	75	<10	190	0.39	4.31	<1	10.92	50	< 5	25	2.00	Quartzite rubble on Quartzite conglomerate

the threshold level in two of the samples. This presumably reflects the occurence of zinc mineralisation in the Dugald River Area.

The background and threshold values were calculated from this group of samples as in those from the Mt. Isa-Cloncurry traverse; (Table IO): The

Table IO: Calculated Background and Threshold Values in Plants, based on six Samples of Triodia pungens from Background Areas at the Dugald River

	ppm of ash			Cu/Zn Ratio	ppm of oven-dry		
	Cu	Pb	Zn		Cu	Pb	Zn
Mean	46.6	<IO	I78	0.34	2.88	<I	IO.67
Standard Deviation	I5.6	-	II3	0.I7	0.86	-	5.93
Threshold	77.8	20	404	-	4.60	2	22.63

results indicate that, while the copper values are only slightly higher in the Dugald River samples, the threshold value for zinc is almost twice that in the Mt. Isa-Cloncurry samples. In view of the relatively small number of samples collected in background regions in the Dugald River Area, however, it is probable that the latter group of samples give a better estimate of the background levels. Hence these values will be used throughout the following discussion.

Table 11 : Triodia pungens. Analyses of Plant Samples from Dugald River Lode Area. Unmilled, dry-ashed material.

No	Locality	Part of Plant	% Ash	ppm of Ash Cu	ppm of Ash Pb	ppm of Ash Zn	Cu/Zn Ratio	ppm of oven-dry material Cu	ppm of oven-dry material Pb	ppm of oven-dry material Zn	ppm of soil (4 - 6 ins) Cu	ppm of soil (4 - 6 ins) Pb	ppm of soil (4 - 6 ins) Zn	Cu/Zn Ratio	Rock Type
40/144	$1150^S/920^W$	Leaves	3.65	45	<10	1800	0,025	1.64	<1	65.7	35	< 25	800	0.044	Shales
40/143	$1150^S/730^W$	Leaves	4.02	60	<10	2200	0,027	2.41	<1	88.44	115	10	500	0.23	Shales
40/142	$1150^S/620^W$	Leaves	4.11	25	<10	440	0,057	1.03	<1	18.08	365	20	620	0.59	Gossanous shales
40/140	$1150^S/430^W$	Leaves	3.82	125	<10	370	0,34	4.77	<1	14.13	500	20	100	5.00	Schists
40/134	$1150^S/180^W$	Leaves	3.04	65	10	2200	0,029	1,97	<0.3	66.8	45	70	4000	0.012	Argillaceous limestone
30/ 6000	$100^N/450^W$	Leaves	3.97	60	<10	2600	0.023	2,33	<1	103	600	120	1300	0.46	Hanging-wall shales
30/ 6002	$100^N/430^W$	Leaves	4,63	15	<10	2600	0.006	0.69	<1	120	400	280	6400	0.063	Hanging-wall shales
30/ 6004	$100^N/420^W$	Leaves	5.12	40	<10	3700	0.011	2,05	<1	189	300	300	3400	0.088	Hanging-wall shales
30/ 6006	$100^N/410^W$	Leaves	3.95	35	<10	3750	0.009	1.38	<1	151	240	550	4500	0.053	Hanging-wall shales
30/ 6008	$100^N/405^W$	Leaves	3.97	70	25	4500	0.015	2.78	0,99	178	240	500	1800	0.13	Hanging-wall shales
30/ 6010	$100^N/400^W$	Leaves	4.18	50	30	5500	0.009	2,09	1,25	230	270	1000	3500	0.077	Hanging-wall shales
40/ 122	$1190^N/350^W$	Leaves	3,81	20	190	6500	0.003	0.76	7.33	247	(at 1 ins) 75	1200	4200	0.018	Footwall shales

The majority of the Lode Area samples, (Table II), were collected from the hangingwall shales to the west of the main mineralised zone. In spite of the compa- atively high copper contents in the underlying soils, the level in the plants exceeds the threshold in only one sample. Most samples are also low in lead, but at the higher soil lead contents some indicate uptake of this metal. In contrast, however, the results for zinc are all above the threshold value of 220 (I3) ppm and the copper : zinc ratios well below the mean background value of 0.44.

Only two samples have been analysed from the Turkey Creek copper showing, (Table I2). The level of copper in both samples exceeds threshold, though the enrichment is less marked than in the case of zinc in the Lode Area samples.

This is further evidenced by study of Figures 3I and 32, where the metal contents in the plant ash and oven-dry material have been plotted against the metal contents in the underlying soil. It is apparent that the level of zinc in the plant increases at a faster overall rate with increasing zinc concentrations in the soil than is the case for the other ore-metals. Both the copper and lead curves indicate inflections, most striking in the case of the latter metal. This suggests that little increase in the plant lead content takes place up to a level of

Table 12 : Triodia Pungens. Analyses of Plant Samples from Turkey Creek Area, Dugald River. Un-milled, dry-ashed material.

No.	Locality	Part of Plant	% Ash	ppm of Ash			Cu/Zn Ratio	ppm of oven-dry material			ppm of soil (4-6 ins)			Cu/Zn Ratio	Rock Type
				Cu	Pb	Zn		Cu	Pb	Zn	Cu	Pb	Zn		
30/6493	$830^N/200^W$	Leaves	2.56	475	<25	130	3.65	12.16	<1	3.33	6800	<5	125	55.0	Copper-stained shales
30/6527	$840^N/200^W$	"	3.02	215	<25	30	9.16	8.30	<1	0.90	5600	<5	100	56.0	"

about 600 ppm in the underlying soil. Above this point, however, the concentration of lead in the plant seems to increase very rapidly over a comparatively small rise in the level in the soil.

Discussion

Field observations indicate that *T. pungens* tends to avoid those areas of very high ore-metal content in the soil. The analyses indicate, however, that it is capable of withstanding appreciable quantities of copper, lead and zinc in the rooting medium, and that increasing soil metal contents are reflected in the plant.

If we assume equivalent concentrations of the ore-metals in the soil, the metal contents in the plant decrease in the order zinc, copper, lead. As indicated by Figures 31 and 32, this order is identical to that of the overall rate of increase of the three metals in the plants, though at the higher soil-lead contents, the rate of increase in this metal takes place at a faster rate than that for zinc. Generally speaking, however, zinc is apparently absorbed at a more rapid rate than copper, which in turn shows a higher rate of uptake than lead. It is interesting to note that the order given agrees with that for the mobility of the three metals in the soils of the Dugald River Area, (Nicolls, 1964). Thus variations in the mobility of the metals in the substrate is apparently reflected in their rate of uptake by plants.

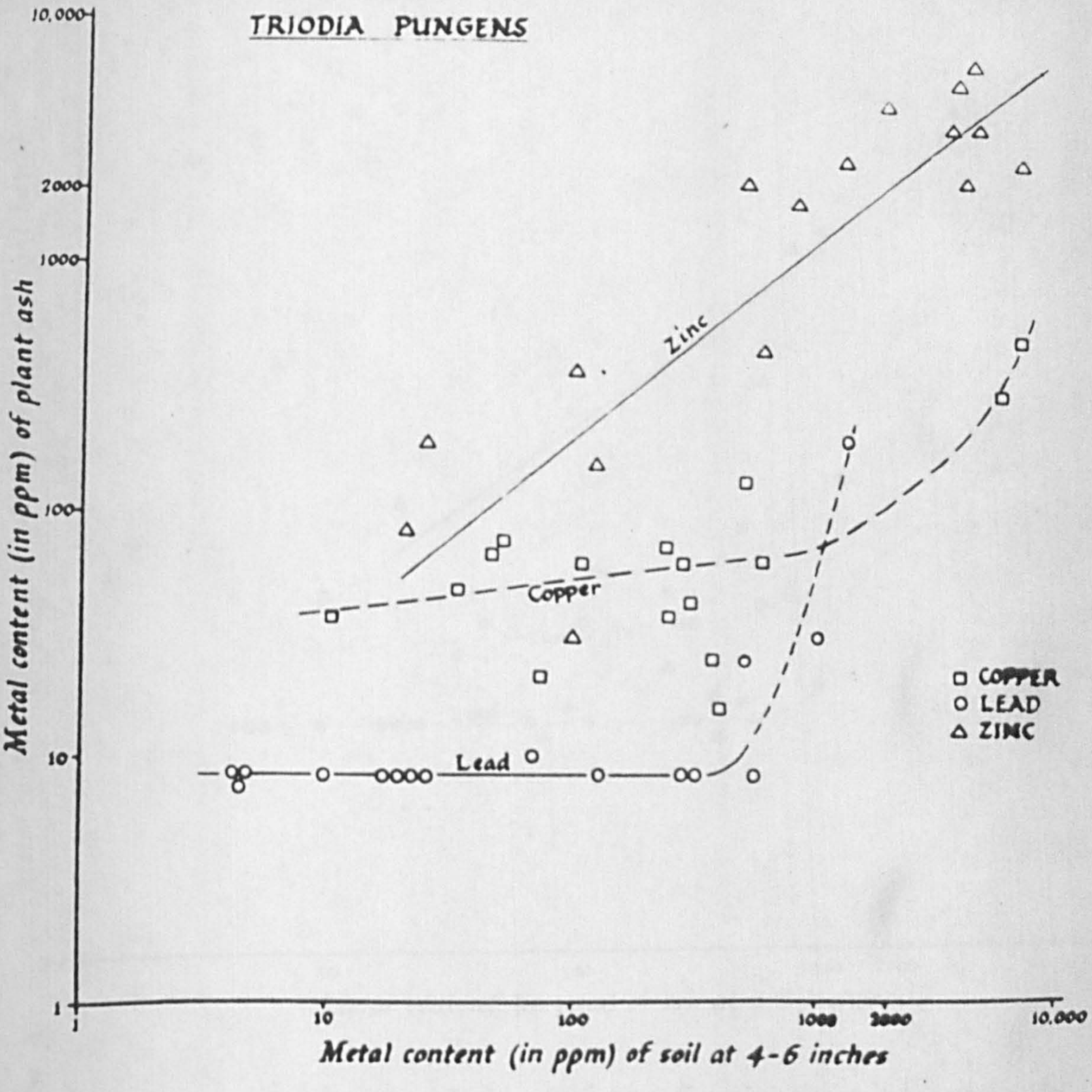


Fig. 3I. Graph of Cu, Pb and Zn Content in the Ash of Leaves of Triodia pungens against the Cu, Pb and Zn Content in the Soil at 4-6 ins. underlying the Sampled Plants.

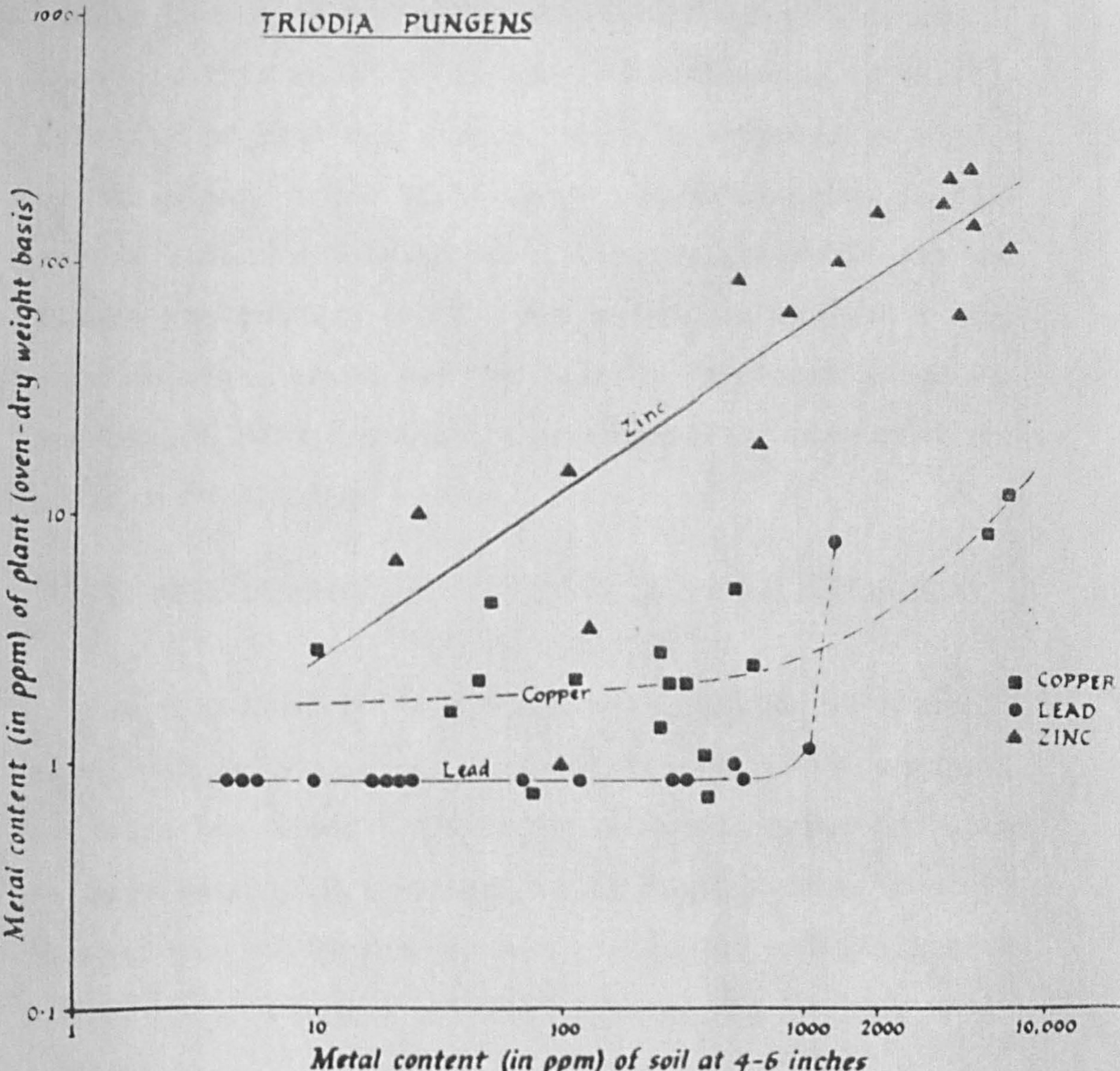


Fig. 32. Graph of Cu, Pb and Zn Content in oven-dry Leaves of Triodia pungens against the Cu, Pb and Zn Content in the Soil at 4-6 ins. underlying the Sampled Plants.

The inflections in the curves, most striking in the case of lead, suggest that the rate of uptake by the plants is not identical at all levels of soil metal content. This could be related to variations in the mobility of lead and copper, or to a suppressive action by the plant at the higher soil concentrations. As discussed later in this section, however, probably the most likely explanation is that the plant has evolved a separate ecotype, which, by its ability to absorb large amounts of copper and lead, is capable of surviving on soils rich in these metals.

(c) Biogeochemistry of Tephrosia sp. nov., (Dugald R. MMC/DMJP No. 5)

As described in Section C, this species is common over both lead-zinc and copper deposits in the region, but also has a scattered distribution in areas not known to be mineralised. Representative samples from these three types of occurrence were collected and the leaves, stems, and where possible the flowers and fruits, analysed separately.

The results from the Lode Area are indicated in Table 13. In this region of lead-zinc mineralisation attention naturally focusses on the plant uptake of these metals, but the analyses for copper also indicate levels which, in most cases, are above threshold. This contrasts with the findings in T. pungens, where the copper content

Table 13 : Tephrosia sp. nov. (Dugald River MMC/DMJP No. 5). Analyses of Plant Samples from Dugald River Lode Area. Un-milled, dry-ashed material.

No	Locality	Part of Plant	% Ash	ppm of Ash			Cu/Zn Ratio	ppm of oven-dry material			ppm of soil (4-6 ins)			Cu/Zn Ratio	Rock Type
				Cu	Pb	Zn		Cu	Pb	Zn	Cu	Pb	Zn		
40/79	$880^S/250^W$	Fruits	2.70	170	<20	1400	0.12	4.59	<1	37.8	25	165	9000	0.003	In bed of drainage gully, on footwall.
		Leaves	6.30	160	<10	3000	0.053	10.08	<1	189					
		Stems	4.84	140	<10	6500	0.022	6.77	<1	314		at 2.5-9 ins			
40/81	$460^S/340^W$	Flowers	4.00	250	<100	3000	0.083	10.00	<4	120	150	415	1440	0.10	Alluvium on lode/footwall junction.
		Leaves	5.36	215	15	9000	0.024	11.52	0.80	482		at 32-36 ins			
		Stems	2.48	115	50	27000	0.004	2.85	1.24	670	150	580	1920		
40/83	$350^S/350^W$	Seeds	5.19	260	<40	720	0.36	13.49	<2	37.36					Lode/footwall junction
		Pods	3.56	115	<10	1000	0.11	4.09	<1	35.6					
		Leaves	4.82	125	40	8570	0.014	6.02	1.93	421					
		Stems	3.12	120	275	16000	0.008	3.74	8.58	500					
40/87 (Seedling)	$365^N/385^W$	Leaves	6.90	175	80	8000	0.022	12.04	5.52	552	140	1300	2100	0.066	Hanging-wall shales
		Stems	4.12	85	50	8000	0.011	3.50	2.06	330					
40/123	$830^N/350^W$	Leaves	8.25	140	35	7500	0.019	11.5	2.89	620					Hanging-wall shales
		Stems	3.13	135	35	15500	0.009	4.22	1.09	485					
40/102	$3520^N/800^W$	Leaves	7.08	120	<10	5500	0.022	8.50	<1	390	70	1200	2100	0.033	Alluvium on lode
		Stems	3.06	90	<10	17500	0.005	2.75	<1	535					

No	Locality	Part of Plant	% Ash	ppm of Ash			Cu/Zn Ratio	ppm of oven-dry material			ppm of soil (4-6ins)			Cu/Zn Ratio	Rock Type
				Cu	Pb	Zn		Cu	Pb	Zn	Cu	Pb	Zn		
40/25	$3550^N/800^W$	Leaves	6.55	190	<10	8000	0.024	12.45	<1	557	70	1200	2100	0.033	Alluvium on lode
		Stems	3.40	125	20	16000	0.008	4.25	<1	544					
40/26	$3850^N/1000^W$	Leaves	7.67	168	10	10500	0.016	12.88	0.76	803	140	225	2780	0.05	Lode
		Stems	3.53	170	30	15000	0.011	4.42	1.06	529					
40/104	$3850^N/900^W$	Leaves	8.79	120	<10	4500	0.027	10.55	<1	395	45	40	3810	0.012	Footwall shales
		Stems	4.28	135	<10	10500	0.013	5.78	<1	450					
40/105	$3940^N/1100^W$	Leaves	8.88	60	<10	1150	0.052	5.32	<1	102	270	600	2550	0.10	Hanging-wall shales
		Stems	4.89	85	<10	3500	0.024	4.15	<1	171					
40/110	$4800^N/1120^W$	Fruits	4.38	175	<50	2400	0.073	7.68	<2	105					Hanging-wall shales.
		Leaves	8.53	90	<10	7750	0.012	7.67	<0.7	660					
		Stems	3.78	70	<10	16500	0.004	2.64	<1	624					
40/116	$5700^N/920^W$	Fruits	4.20	175	<50	750	0.23	7.34	<2	31.5	700	60	2300	0.30	Footwall shales.
		Leaves	6.89	185	<10	6400	0.029	12.74	<1	440					
		Stems	3.26	175	<10	9200	0.019	5.70	<1	229					

in the Lode Area samples rarely exceeded the anomaly threshold. Moreover, the soils underlying the latter group of samples are, in general, richer in copper than those of the Tephrosia sp. nov. samples. Hence the latter species shows a higher degree of copper enrichment than T. pungens.

The lead values again remain at the lower limit of detection in the majority of samples, but the level of zinc is considerably above the threshold value throughout. Likewise, the copper:zinc ratios are appreciably below the mean background value of 0.44, (Table 8). With the exception of the sample discussed below, the level of zinc in the ash of the leaves and stems is above that in the underlying soil. In contrast, comparison with the results for T. pungens, (Table II), shows that in this species the maximum zinc content in the ash of the leaves is of the same order as the highest value in the associated soils. It appears, therefore, that Tephrosia sp. nov. will absorb a greater quantity, not only of copper but also of zinc, than T. pungens when growing in the same locality.

In sample 40/79, however, the concentration of zinc in the underlying soil exceeds that in either the ash of the leaves or stems of the plant. This sample was collected from a plant growing in a small gully carrying zinc-rich particles away from the Lode. Hence the near-surface soils at this locality are probably richer in zinc than the deeper horizons at which the plant roots, (root penetration of up to 2 ft. along the bedding planes of a shale was observed in this species). This may explain the disparity between the ratio of the zinc content in the plant to that in the soil in this sample compared with the remainder from the Lode Area.

Analyses of this species from plants growing in alluvial soils provide further evidence that it obtains the bulk of its nutrients from the deeper soil layers. Samples 40/8I, I02 and 25 were collected from shrubs growing on coarse alluvium on terraces flanking the creeks which traverse the Lode zone. This material is largely derived from the barren Quartzite Range, and hence is low in the ore-metals. In spite of the comparatively low zinc values in the near-surface soils, the plants all indicate very high enrichment in this metal. Thus the plant analyses from these areas confirm the presence of the Lode at depth, even though it is not exposed on the surface.

The two samples of living material from the Turkey Creek Area, (Table I4), collected from the malachite-stained shales, indicate above-threshold values for copper. The results are in most cases higher than in the *T. pungens* samples from this area, (Table I2), even though the latter were collected from soils richer in copper. The sample of dead stems of *Tephrosia* sp. nov.

Table 14 : Tephrosia sp.nov. (Dugald River MMC/DMJP No. 5) Analyses of Plant Samples from Turkey Creek Area, Dugald River. Un-milled, dry-ashed material.

No	Locality	Part of Plant	% Ash	ppm of Ash			Cu/Zn Ratio	ppm of oven dry material			ppm of soil (4-6 ins)			Cu/Zn Ratio	Rock Type
				Cu	Pb	Zn		Cu	Pb	Zn	Cu	Pb	Zn		
40/21	$830^{N}/170^{W}$	Fruits	4.87	266	<66	333	0.86	12.9	<3	16.2	1740	<5	70	24.85	Copper-stained shales.
		Flowers	7.38	160	<4	160	1.00	11.8	<1	11.8					
	Turkey Creek	Leaves	8.84	650	<10	120	5.41	57.46	<1	10.60					
		Stems	4.16	750	<10	190	3.95	31.20	<1	7.90					
40/19	$830^{N}/220^{W}$ Turkey Creek	Leaves	5.86	1250	<10	240	5.20	73.25	<1	14.0	1800	<5	70	25.71	Copper-stained shales.
		Stems	3.85	650	<20	310	2.09	25.02	<1	11.9					
40/20 (Dead)	$790^{N}/225^{W}$ Turkey Creek	Stems	1.43	225	<10	220	1.02	3.21	<1	3.15	1800	<5	70	25.71	Copper-stained shales
40/16 (Dead)	$00-25^{E}$ dissected area E of Turkey Creek	Stems	1.96	138	<50	250	0.55	2.70	<1	4.90	40	<5	29	1.38	Calc-silicates

from this locality, however, contain a much lower copper content, though the concentration of this metal in the underlying soil is of the same order. Thus the level of copper in the plants apparently decreases as the plant dies. Zinc is also present in anomalous amounts in some of the samples, reflecting the enrichment in this metal, though to a lesser degree than that of copper, in the soils over the mineralised zone.

The distribution of Tephrosia sp. nov. in areas not known to be mineralised, and the results of the geochemical traverses at several of the areas of occurrence, have been described in the previous section. The analyses of several samples from these localities are indicated in Table I5. Sample 40/I49, collected from the shrub occurrence at 9000N/400W, (Fig. 24), contains anomalous concentrations of zinc, although the values do not approach those in the Lode Area samples. Moreover, as indicated in Figure 26, the geochemical traverse at this locality defines a small zinc anomaly in the underlying near-surface soil. This occurrence lies at approximately the same stratigraphic horizon as the Lode, which apparently lenses out some 3000 ft. to the south. In view of the anomalous zinc contents in both plant and soils, however, it is possible that the shrubs mark a lateral extension of the zone of lead-zinc mineralisation.

Further north the shrub was found at I8700N/2000E

Table 15 : Tephrosia sp. nov. (Dugald River MMC/DMJB No. 5) Analyses of Plant Samples from Areas not known to be Mineralised, Dugald River. Un-milled, dry-ashed material.

No	Locality	Part of Plant	% Ash	ppm of Ash			Cu/Zn Ratio	ppm of oven dry material			ppm of soil (4-6 ins)			Cu/Zn Ratio	Rock Type
				Cu	Pb	Zn		Cu	Pb	Zn	Cu	Pb	Zn		
40/149	9000^{N}/ 400^{W}	Leaves	8.88	50	<10	460	0.11	4.44	<1	40.74	25	<10	80	0.31	Quartzite rubble
		Stems	4.90	90	<10	340	0.26	4.40	<1	16.66					
40/145	$18,000^{N}$/ 2000^{E}	Leaves	10.65	60	<10	90	0.67	6.39	<1	9.59	125	<10	35	3.57	Sheet wash cover
		Stems	4.71	90	<10	140	0.64	4.34	<1	6.71					
40/146	$18,000^{N}$/ 2100^{E}	Leaves	9.78	60	<10	120	0.50	5.86	<1	11.73	120	<5	18	6.66	Sheet wash cover
		Stems	7.14	65	<15	130	0.50	4.67	1.07	9.28					
40/147	$18,000^{N}$/ 2300^{E}	Leaves	9.50	50	<10	120	0.42	4.75	<1	11.40	30	<5	24	1.25	Sheet wash cover
		Stems	5.22	65	<10	120	0.54	3.40	<1	6.26					
40/152 (dead)	$16,400^{N}$/ 700^{W}	Stems	2.54	165	<10	240	0.69	4.20	<1	6.09	25	<15	30	0.83	Quartzite rubble on fragmental calc-silicat
40/24 (dead)	$24,000^{N}$/ 3600^{W}	Stems	2,71	145	<10	155	0.93	3.92	<1	4.19	45	<5	16	2.81	Quartzite rubble on fragmental calc-silicat

on a broad, low-lying interfluve veneered by sheet wash alluvium. The soils at this locality contain anomalous concentrations of copper, (Fig. 28), while profile sampling indicates that the copper content increases with depth. The plant samples from this locality, Nos. 40/I45, I46, and I47, however, show little evidence of copper enrichment. The level in the plant ash, with one exception of 90 ppm, are all below-threshold, though on an oven-dry weight basis the majority of the leaves and stems contain slightly anomalous copper contents.

The two samples of dead material, Samples 40/I52 and 24, were collected from coarse quartzitic debris containing low amounts of the ore-metals. When expressed on the ppm ash basis, the copper values, and in Sample 40/I52, the zinc content, are above-threshold. On the oven-dry weight basis, however, the copper contents in the two samples approximate to the threshold value of 4 ppm, while the level of zinc is below the threshold value of I3 ppm.

The relationship between the ore-metal content in the plant and the concentration in the underlying near-surface soil is indicated in Figures 33 and 34. As was the case in T. pungens, the concentration of zinc, copper and lead shows a general decrease in the plant in the order named. Similarly, the curve for zinc indicates a more rapid overall increase in the plant with rising

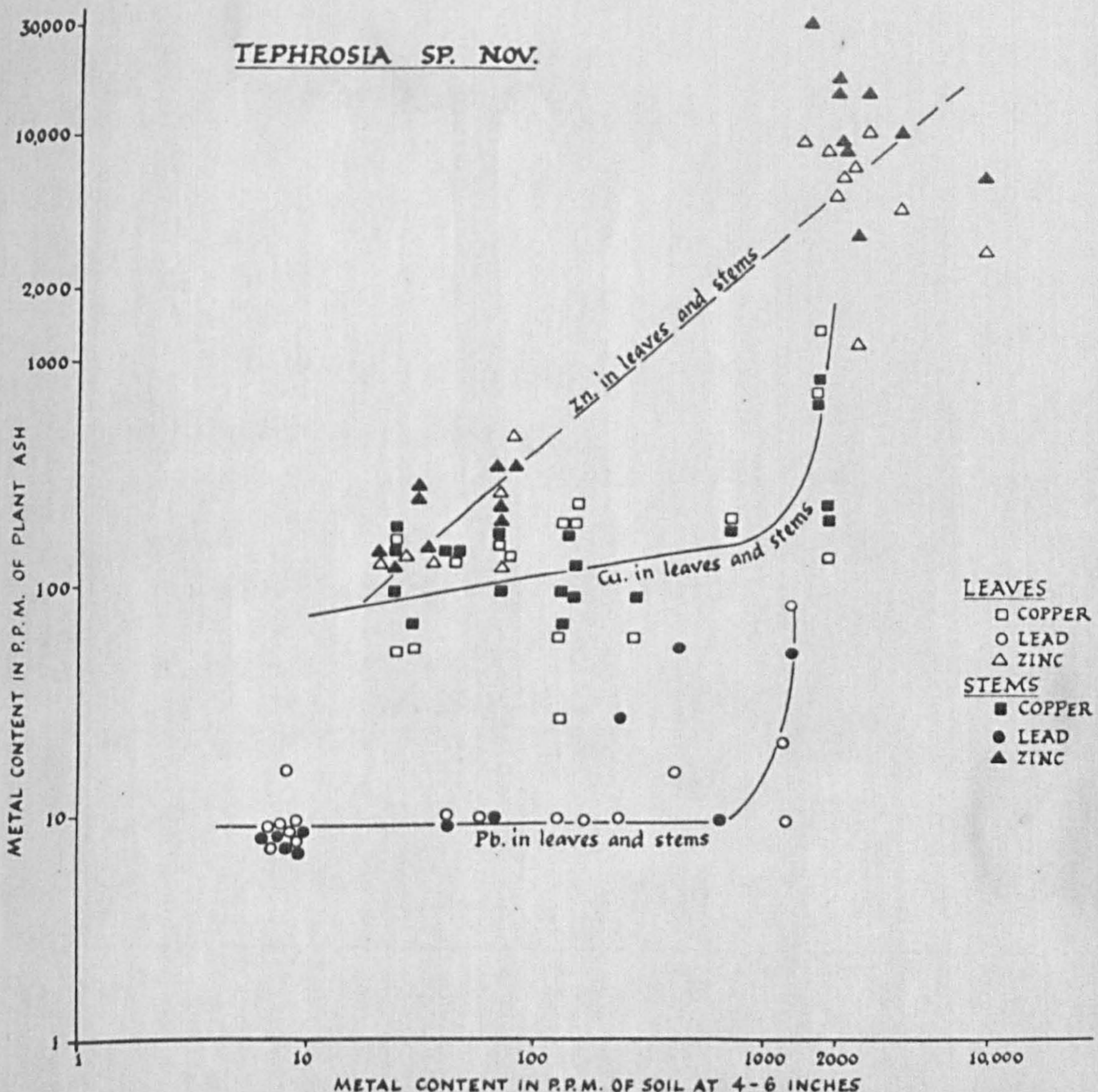


Fig. 33 Graph of Cu, Pb and Zn Content in the Ash of Leaves and Stems of *Tephrosia* sp. nov. against the Cu, Pb and Zn Content in the Soil at 4-6 ins. underlying the sampled Plants

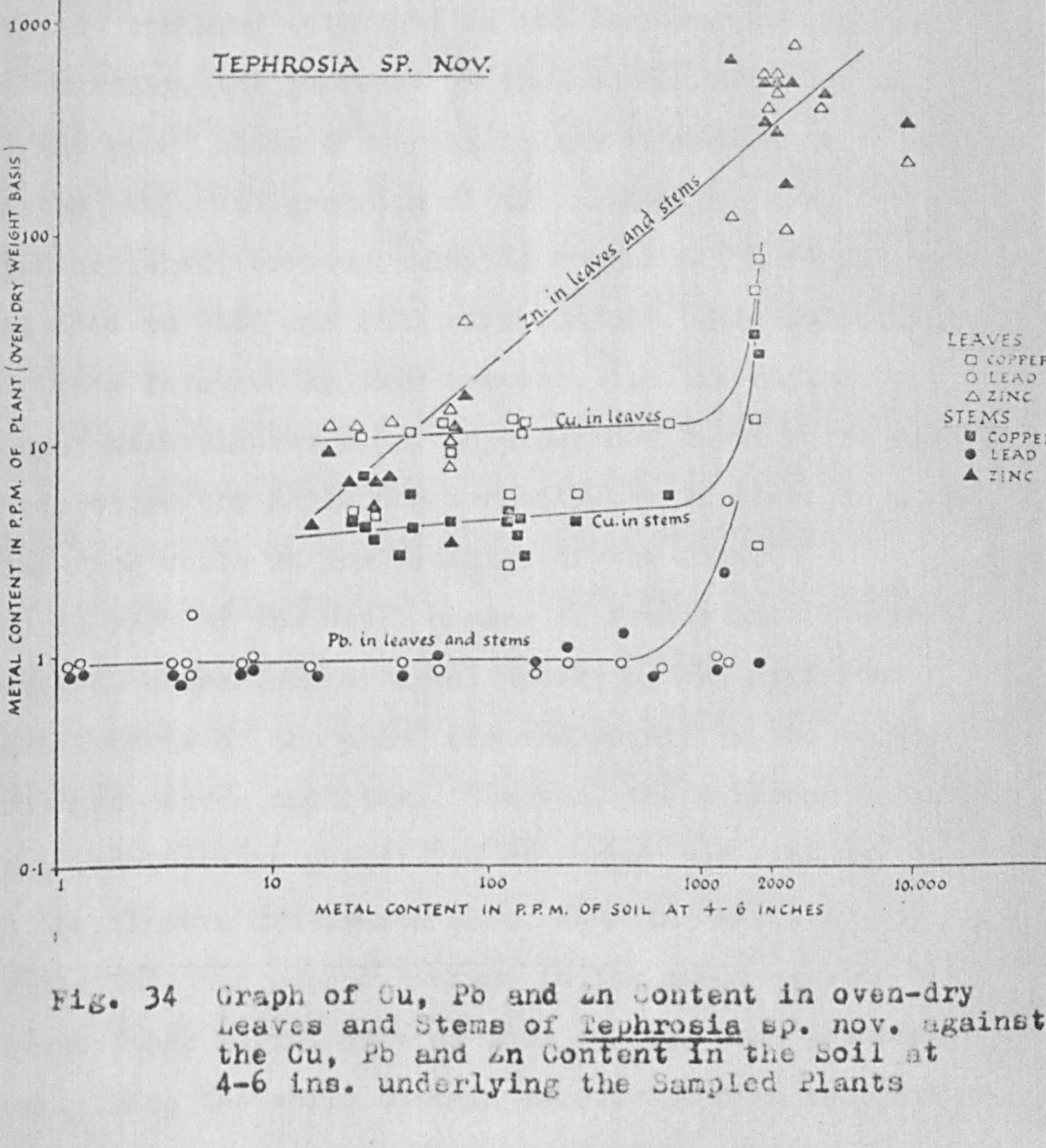


Fig. 34 Graph of Cu, Pb and Zn Content in oven-dry Leaves and Stems of Tephrosia sp. nov. against the Cu, Pb and Zn Content in the Soil at 4-6 ins. underlying the Sampled Plants

concentrations of zinc in the soil than is the case for copper or lead. At higher soil contents of the latter metals, however, the slope of the curves increase sharply, indicating a rapid rise in the plant metal content compared with that in the near-surface soils. In contrast, the increase in the concentration of zinc in the plant shows a roughly linear relationship to that in the soil. Two grouping of the points for zinc may be distinquished, corresponding to ranges of 20 to I00 ppm and I500 to 9000 ppm soil zinc content. This reflects the habitats favoured by this species, i.e. in regions of copper mineralisation, or in areas not known to be mineralised, where the soils are normally low in zinc, or on the zinc-rich soils in the vicinity of the Lode.

In view of the small number of fruits and flowers sampled, comparison of metal uptake by the different aerial parts of the plant centres mainly on the results from the leaves and stems. However, the analyses indicate that considerable quantities of copper and zinc may occur in the flowers and fruits also. Thus in Sample 40/83, (Table I3), the copper content in the seeds exceeds that in any other aerial part of this species from the Lode Area. Where the soils contain relatively high concentrations of this metal, however, as at Turkey Creek, then the fruits and flowers are low in copper compared with the level in the leaves and stems. Similarly, the flowering parts in those samples from the Lode Area are appreciably lower in lead and zinc than the corresponding leaves and stems.

Reference to the graph of the metal content in the leaves plotted against that in the stems, (Fig. 35), shows that, expressed on the ppm ash basis, the stems generally contain higher zinc contents than the leaves. This is especially marked in those samples with higher values for the metal. The distribution of copper and lead is more variable, in some cases the leaves showing maximum enrichment while in others it is the stems.

Since the ash content varies between the leaves and stems, comparison of metal content between the two organs is more valid when the results are expressed on the oven-dry weight basis. In this case the majority of samples show maximum enrichment in copper and zinc in the leaves, while the distribution of lead shows no distinct pattern, (Fig. 35). The variation in the level of copper between the two organs is especially striking, as evidenced by Figure 34 where separate curves have been drawn for the copper content in the leaves and stems compared with that in the soil.

Discussion

The biogeochemistry of *Tephrosia* sp. nov. departs in several important respects from that of *T. pungens*.

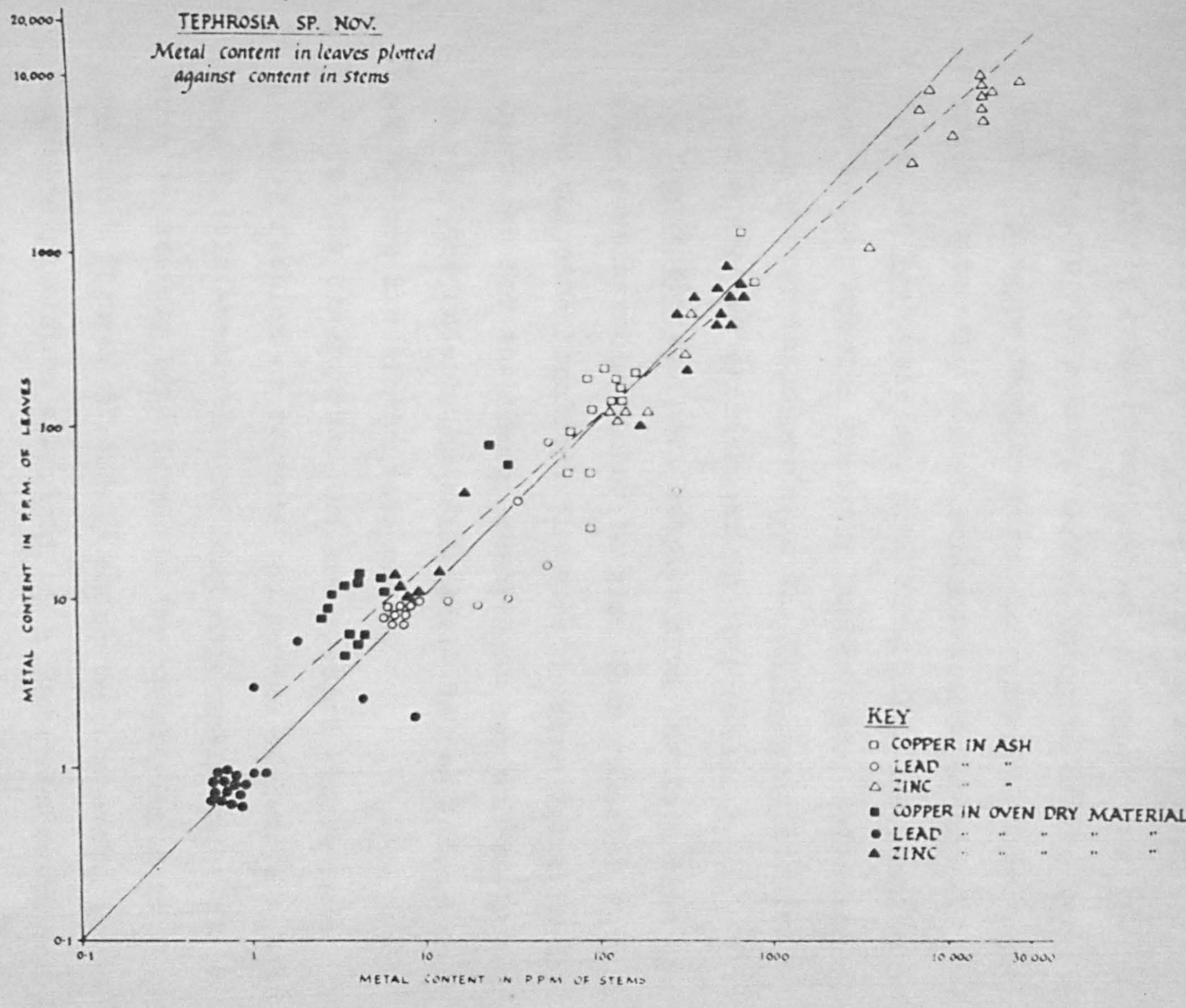


Fig. 55. Graph of Cu, Pb and Zn Content in Leaves : Stems in Tephrosia sp. nov.

In the first place, the samples of both leaves and stems of the first-named species from the Lode Area indicate appreciably greater enrichment in copper than the leaves T. pungens. This has occurred in spite of the fact that the T. pungens samples were, in general, collected from soils containing higher concentrations of copper than those of Tephrosia sp. nov. Similarly, the samples of the latter species from the Turkey Area, collected from soils poorer in copper than the T. pungens samples, show a greater encrichment in this metal.

Tephrosia sp. nov. samples from the Lode Area are also considerably richer in zinc than those of T. pungens from the same locality. Thus the maximum value in the plant ash for the former species is approximately twice that in the underlying soil, while in the latter the two values are of the same order.

On the other hand, the two species behave in a similar fashion as regards the uptake of lead. In both, very little absorption of lead apparently takes place up to a relatively high level in the underlying soil. Comparison of Figures 3I and 33 indicates, however, that lead seems to pass into the plant at a lower concentration in the soil in the case of T. pungens than in Tephrosia sp. nov. Thus the inflections in the curves of the plant lead content : soil lead content occur at soil concentrations of 600 and I000 ppm respectively. This suggests that

Tephrosia sp. nov. can withstand higher levels of lead in the soil than T. pungens, a suggestion which is borne out by their distribution in the field. The former species also differs from T. pungens in that the change in the slope of the curve for copper is much more abrupt, (Figs. 3I and 33). These variations in the rate of metal uptake by the different species are, however, more fully discussed in a later section.

The oven-dried leaves of this species show a marked enrichment in copper compared with the concentration in the corresponding stems. Although the variation is less striking, a similar enrichment is apparent in the case of zinc. This agrees with the findings of Rankama, (I940), who considers that the bulk of the metal absorbed by plants is carried upwards in solution in the transpiration stream, and precipitated in the leaves where evaporation is highest.

The same author has also commented on the decided enrichment shown by plant organs with small ash contents. This is especially marked in the case of the zinc content in the ash of the Tephrosia sp. nov. where the relationship between the metal content in the leaves and stems is completely reversed from that obtained when the results are expressed on the oven-dry weight basis. Similarly, the samples of dead stems from areas not known to be mineralised, (Table I5), where the ash content is again low, show relatively high copper contents in the ash compared with the level in other samples from this type of environment. When expressed on the oven-dry weight basis, however, the level in the dead stems is of the same order as that in the living material.

While the occurrences of Tephrosia sp. nov. in regions apparently devoid of mineralisation may in some cases mark the site of minor zinc and copper anomalies in the underlying soil, plant analysis from these localities has only yielded above-threshold values for the former element. In view of the deep-rooted nature of this species, (Plate I6), and the observation that at one occurrence of this type the copper content in the soil increased with depth, one might have expected anomalous concentrations of this metal in some of the samples. Moreover, the evidence from the Lode Area samples indicates that the plant gains the greater part of the absorbed metal from the deeper layers in the soil.

It would seem, therefore, that higher concentrations of copper must be present in the substrate before this species will show significant enrichment than is the case with zinc. This agrees with the evidence presented in the graphs of the plant metal content : soil metal content, (Figs. 33 and 34), and is probably related to the lower mobility of the former element compared with that of zinc.

(d) Biogeochemistry of *Polycarpaea glabra*

Representative samples of this herb were collected from the lead-zinc Lode and bordering shales, from the malachite-stained shales of the Turkey Creek Area, and from an un-mineralised locality in the Quartzite Range. The flowers, leaves and stems have been analysed separately, (Table I6), while in some samples the stems have been further separated into young and old material.

The majority of the Lode Area samples indicate above-threshold values for copper. Sample 40/I38 was collected from a zone of copper mineralisation in the hangingwall of the Lode, and here the old stems contain I300 (39.6) ppm copper, compared with a soil copper content of 5700 ppm. The various aerial parts of this sample show copper:zinc ratios approaching or above the mean background value of 0.44, but otherwise the ratios are generally well below this figure. Only one sample contains appreciable amounts of lead, though the majority indicate detectable concentrations of this metal. On the other hand, the zinc results are all well above the threshold level.

The distribution of this species in the Turkey Creek Area is restricted to the copper-rich soils immediately overlying the main belts of malachite-stained shales. While all the samples from this area contain above-threshold values for copper, the degree of enrichment

Table 16 : Polycarpaéa Glabra. Analyses of Plant Samples from the Dugald River Area.
Un-milled, dry-ashed material.

No.	Locality	Part of Plant	% Ash	ppm of Ash			Cu/Zn Ratio	ppm of oven-dry material			ppm of soil (4-6 ins)			Cu/Zn Ratio	Rock Type
				Cu	Pb	Zn		Cn	Pb	Zn	Cu	Pb	Zn		
40/71	$1710^{S}_{W}/270^{W}$	Flowers	3.39	370	<10	2,600	0.14	12.54	<1	88					Gossanous shales
		Leaves	6.55	206	<10	3,800	0.054	13.49	<1	249					
		Stems	2.95	275	<10	1,350	0.20	8.11	<1	40					
40/138	$1150^{S}_{W}/365^{W}$	Flowers	4.01	335	20	1,200	0.28	13.43	0.8	48	5700	35	480	11.87	Copper vein
		Leaves	6.07	230	<20	1,200	0.19	13.96	1.21	73					
		Young stems	2.51	500	15	1,600	0.31	12.55	0.38	40.16					
		Old stems	3.03	1300	<20	1,400	0.93	39.6	<0.61	42.70					
30/6018	$100^{N}_{W}/370^{W}$	Flowers	4.67	166	874.5	10,725	0.015	7.45	40.83	500	500	6000	10000	0.050	Lode
		Stems	3.18	145	650	17,500	0.008	4.61	20.66	600					
40/112	$4800^{N}_{W}/1120^{W}$	Flowers	3.91	200	20	12,000	0.017	7.82	1	469					Hangingwall shales
		Leaves	5.71	70	<20	34,000	0.002	4.00	<1.04	1943					
		Young stems	2.61	170	<20	42,000	0.004	4.44	<1	1097					
		Old stems	2.73	275	15	22,000	0.012	7.53	0.41	602					
40/27	$15,600^{N}_{W}/1200^{W}$	Flowers	4.54	180	80	1,000	0.18	8.17	3.63	45.40	15	<10	7.5	2.0	Bed of creek, on quartzite rubble
		Leaves	5.65	120	40	820	0.15	6.78	2.26	46.33	(stream sediment sample)				
		Stems	2.58	230	<20	520	0.44	5.93	<1	13.45					
40/151	$15,600^{N}_{W}/1200^{W}$	Flowers	3.76	125	<10	700	0.18	4.70	<1	26.32	38	<10	35	1.08	Side of creek, quartzite
		Stems	2.43	175	<20	400	0.44	4.25	<1	9.72	(surface soil)				
40/18	$00/30^{S}$ Turkey Creek	Flowers	6.42	250	20	240	1.04	16.05	1.28	15.41	3600	<5	145	24.82	Copperstained shales
		Stems	2.11	350	<20	320	1.09	7.39	<1	6.76					

No.	Locality	Part of Plant	% Ash	ppm of Ash			Cu/Zn Ratio	ppm of oven-dry material			ppm of soil 4-6 ins			Cu/Zn Ratio	Rock Type
				Cu	Pb	Zn		Cu	Pb	Zn	Cu	Pb	Zn		
40/171	830N/200W Turkey Creek	Flowers	4.26	340	140	340	1.0	14.48	5.95	14.48					Copperstained shales
		Leaves	5.51	550	70	250	2.2	30.3	3.83	13.75	6800	<5	123	55.0	
		Stems	4.30	1300	<25	180	7.22	55.9	<1.07	7.74					
40/22	830N/190W Turkey Creek	Flowers	4.90	250	<20	220	1.14	12.25	<1	10.77					Copperstained shales
		Leaves	4.83	200	<5	155	1.48	8.88	<1	6,33	6000	<5	123	48.78	
		Stems	2.66	285	<5	125	2.28	7.58	<1	3.32					
40/172	830N/190W Turkey Creek	Flowers	4.38	170	<100	280	0,60	7.44	<4.38	12.26					Copperstained shales
		Leaves	6.37	230	<25	260	0.88	14.63	1.6	16.56	6000	<5	123	48.78	
		Stems	3.34	615	35	210	2.93	20,54	1.16	7,01					

is generally below that for Tephrosia sp. nov. in spite of the fact that the latter species avoids the regions of maximum copper staining. (Plate I8). Comparison of the copper values in P. glabra with those of T. pungens from the Turkey Creek Area, (Table I2), indicates that the general level tends to be slightly higher in the former species. Several of the samples also contain above-threshold values of zinc, reflecting the minor amounts of zinc, as evidenced by the geochemical results, occurring with the copper mineralisation. The comparatively high lead concentrations in some of the plant samples are less easily explained, however, since the geochemical analyses indicate that this metal is virtually absent from the soils of the area.

A similar anomalous situation occurs in the two samples of P. glabra from the Quartzite Range, Samples 40/27 and I5I, (Table I6). As described in the previous section, the plant occurs along several of the creeks draining this un-mineralised formation. The stream sediments and surface soil underlying the plant samples are consequently low in the ore-metals, but in contrast several of the aerial parts from the two samples contain anomalous amounts. The enrichment in lead and zinc is most marked, the flowers of one sample containing 80 (3.63) ppm lead and I000 (45.4) ppm zinc, compared with levels of $<$ I0 and 7.5 ppm respectively in the stream sediments in which the plant was rooted.

It is interesting to note, however, that in spite of the variations in the copper and zinc contents between the two samples, the copper:zinc ratio for the flowers and stems remains the same in both samples. Moreover, the ratio in the stems is equal to the mean background value. Thus in these samples the ratio of copper to zinc in the plants shows a closer correlation with the background concentrations of these metals in the substrate than do the concentrations of the individual metals in the plants.

The distribution of the ore-metals within the aerial parts of P. glabra shows wide variation. It will be recalled that in Tephrosia sp. nov. the highest concentrations of copper and zinc normally occurred in the leaves. Lead was more variable. In P. glabra, however, the results indicate that all parts of the plant may contain large amounts of ore-metal, and that the distribution within the plant varies according to the concentration of the indidividual metals in the substrate. At lower levels of soil copper the higher concentrations of this element occur in the flowers, while as the copper content in the soil increases the stems show maximum enrichment. Similarly, in those samples from areas of low soil zinc content the flowers generally contain the highest concentrations in the plant, whereas in the samples from the zinc-rich soils of the Lode Area the maximum values occur in the leaves. In the samples with detectable amounts of lead, however, the flowers almost invariably show the highest degree of enrichment in this metal.

Discussion

Perhaps the most striking feature arising from the analyses of Polycarpaea glabra is the anomalous metal contents in the samples from the un-mineralised Quartzite Range. Also of interest is the high lead contents occurring in the Turkey Creek samples, where the soils are very low in this metal.

These disparities may be related to the fact that P. glabra is a perennial species, and hence over a number of years the metal concentrations in the plant may build up to a level exceeding that in shorter-lived plants. A second possible explanation is that the species, initially adapted to growth in soils with toxic amounts of the ore-metals, (by an ability to accumulate large quantities of these metals without injury), is now in progress of migration to barren areas and has retained this characteristic. This, however, may only account for the anomalous metal contents in the Quartzite Range samples. Little evidence exists to support this hypothesis, but it could explain the distribution pattern of P. glabra, i.e. both in the vicinity of the ore-deposits and in un-mineralised areas.

It is realised that neither of these explanation offer a really satisfactory explanation of these anomalous values. There is some evidence, however, that these phenomena may be a characteristic of species which show an association with mineralisation. Thus, in their study of the vegetation of the Katanga ore-deposits, Duvigneaud and Denaeyer-de-Smet, (1963), found that _Uapaca robynsii_ De Wild and _Olax obtusifolia_ De Wild, species present over copper deposits and here rich in this metal, also contained anomalous copper contents when occurring in barren regions. No explanation, however, was put forward to account for this observation.

The precise reason for the variation in the distribution of the ore-metals within the aerial parts of _P. glabra_ is also unclear. The fact that the maximum value for copper is found in the stems, that for lead in the flowers and that for zinc in the leaves contrasts with the findings for _Tephrosia_ sp. nov. Here both the copper and zinc maxima occurred in the leaves, while the distribution of lead varied.

Moreover, at lower concentrations of soil zinc and copper, it is the flowers which generally show the greatest degree of enrichment in these metals. Although it may not have a direct bearing on these variations, the investigation by Wood and Sibley, (1949), into the distribution of zinc in oat plants is of interest. These authors suggest that the developing inflorescences may act as a "sink" for zinc. Considerable amounts of this metal were found in the flowers as the oat plants reached maturity. It seems possible that a similar mechanism may be in operation in P. glabra, and may account for the variations in metal distribution within the plant. Extensive experimental work is required before these can be satisfactorily explained, however.

Comparison with the results from the analyses of T. pungens from the Lode Area indicates that P. glabra shows a decidedly greater degree of zinc enrichment. The maximum value in the ash samples from this area is several times greater than that in the soils underlying the plant, while in T. pungens the two values are of the same order. Zinc enrichment in P. glabra is also higher than in Tephrosia sp. nov., but this species tends to avoid those regions of maximum soil zinc content, while the former is apparently well-adapted to these conditions.

The maximum value for lead is also higher in the species under discussion than in those described previously, but again the field observations indicate that P. glabra can withstand higher concentrations of this metal than the others. In contrast, however, the P. glabra samples from the Turkey Creek copper occurrence tend to be lower in this element than the samples of Tephrosia sp. nov., in spite of the fact that the latter species occurs on soils containing lower copper contents. Comparison with the T. pungens samples from this region, which here were collected from soils containing equivalent copper concentrations to the P. glabra samples, indicates that the level of copper is slightly higher in the latter species.

These variations between the metal uptake by P. glabra and Tephrosia sp. nov. may in part be related to the fact that the former is a herb while the latter is a shrub. Hence, the greater age of the material sampled in Tephrosia sp. nov. probably accounts for the comparatively high enrichment shown by the samples from Turkey Creek. Both species, however, apparently have the ability to absorb larger amounts of the ore-metals than T. pungens. This may form an adaptive mechanism which allows these species to survive on the metal-rich soils over the ore-deposits, while T. pungens tends to avoid them.

(e) Biogeochemistry of Eriachne mucronata

This species forms the dominant member of the plant assemblage over the lead-zinc Lode, and is also common in the vicinity of the majority of the copper showings within the area. It also occurs, though to a lesser extent, in regions apparently devoid of mineralisation, but in at least one such locality the plant is apparently associated with anomalous copper and zinc contents

Table 17: *Eriachne mucronata* Analyses of Plant Samples from Dugald River Lode Area.
Un-milled, dry-ashed material.

No.	Locality	Part of Plant	% Ash	ppm of Ash Cu	ppm of Ash Pb	ppm of Ash Zn	Cu/Zn Ratio	ppm of oven-dry material Cu	ppm of oven-dry material Pb	ppm of oven-dry material Zn	ppm of soil (4-6 ins) Cu	ppm of soil (4-6 ins) Pb	ppm of soil (4-6 ins) Zn	Cu/Zn Ratio	Rock Type
40/12	3050^{S}/150^{W}	Leaves & Stems	2.6	85	<10	480	0,18	2,2	<1	12.5	750	10	220	3.40	Shales with gossan
40/14	1600^{S}/550^{W}	"	3.0	45	<7.5	850	0.053	1,5	<1	25.5	1100	20	600	1.83	Footwall shales
40/141	1150^{S}/430^{W}	"	2.78	60	<10	360	0.166	1.67	<1	10.00	500	20	100	5.00	Schists
40/139	1150^{S}/365^{W}	"	3.79	1500	<10	1800	0.83	56.8	<1	68.22	5700	35	480	11.87	Copper vein
40/136	1150^{S}/310^{W}	"	5.09	75	<10	880	0.085	3.81	<1	44.79	2700	55	220	12.27	Hangingwall shales
40/133	1153^{S}/256^{W}	"	3.12	50	<10	3000	0.017	1.56	<1	93.60	1100	440	4800	0.23	Lode/footwal junction
40/135	1150^{S}/232^{W}	"	3.07	35	<10	8500	0.004	1.07	<1	261	190	150	24000	0.008	Footwall shales
40/11	00/260^{W}	"	5.3	60	<10	13500	0,004	3.18	<1	867	35	75	15000	0.002	Footwall shales
30/6010	100^{N}/400^{W}	"	4.82	50	15	4000	0.012	2.41	0.72	193	270	1000	3500	0.077	Hangingwall shales
30/6012	100^{N}/395^{W}	"	3.98	225	30	3750	0.060	8.95	1.19	149	280	1500	3600	0.078	Hangingwall shales
30/6014	100^{N}/390^{W}	"	4.70	60	90	3500	0.017	2.82	4.23	164	270	2000	4800	0.056	Lode/hanging wall junctio
30/6016	100^{N}/380^{W}	"	3.52	50	520	4500	0.011	1.76	18.30	158	300	1500	5000	0,060	Lode

No.	Locality	Part of Plant	% Ash	ppm of Ash			Cu/Zn Ratio	ppm of oven-dry material			ppm of soil (4-6 ins)			Cu/Zn Ratio	Rock Type
				Cu	Pb	Zn		Cu	Pb	Zn	Cu	Pb	Zn		
30/6018	$100^N/370^W$	Leaves & Stems	4.73	65	1050	5500	0.012	3.07	49.67	260	500	6000	10000	0.050	Lode
30/6022	$100^N/330^W$	"	4.50	75	160	5000	0.015	3.37	7.20	225	150	2000	3500	0.043	Footwall shales
40/120	$1207^N/690^W$	"	5.05	25	315	6500	0.004	1.26	15.90	328	180	3500	6340	0,028	Western Lode
40/118	$1200^N/640^W$	"	3.60	65	20	4200	0.015	2.34	0.72	151	1360	1300	5640	0,241	Graphitic shales
40/121	$1190^N/350^W$	"	4.2	45	<10	9000	0.005	1.89	<1	382	50	550	10000	0.005	Footwall shales
40/96	$2200^N/460^W$	"	3.85	35	40	4500	0.007	1.35	1.54	173	60	2600	6400	0,009	Footwall shales
40/99	$3020^N/700^W$	"	4,54	25	540	4500	0.005	1.13	24.5	204	35	2500	65000	0,0005	Lode

in the underlying soil.

Owing to the difficulty of separating leaves and stems in this species, these two parts have been analysed together. At the time of collection the seeds had been shed, and the small fraction of the analysed material comprised by the flowers can therefore be safely neglected.

With the exception of Sample 40/I39, (Table I7), which was collected from a zone of copper mineralisation in the hangingwall, the majority of the Lode Area samples contain low copper contents. Only in two samples do the values significantly exceed the threshold, though the majority of the samples were collected from soils containing comparatively high copper contents. Approximately half of the samples contain detectable amounts of lead, a higher proportion than in those species discussed prevously. Zinc is present in anomalous quantities in all samples, but the enrichment in this metal is less striking than in Tephrosia sp. nov. or P. glabra. In these species the maximum values in the ash was several times that in the soils underlying the sampled plants, while in E. mucronata the reverse is the case. Hence, in this respect, the zinc uptake in the latter species is closer to that in T. pungens where the zinc maxima in the two media were of the same order.

The two samples from the Turkey Creek copper occurrence (Table I8), contain below threshold copper contents, [illegible] though the copper:zinc ratios in both samples are well above the mean background value of 0.44. The level of copper contrasts markedly with that in Sample 40/I39 from the Lode Area, where the plant contains I500 (56.8) ppm compared with a soil copper content of 5700 ppm. Zinc is also low, and in this case the values are appreciably below the background level of I20 ppm.

The reason for these low concentrations of ore-metal, especially striking in the case of copper in view of the very high copper contents in the underlying soil, is unclear. Most of the samples were collected towards the end of the dry season, and it is possible that in the Turkey Creek samples dessication was more advanced than in samples from other localities. As we have seen in Tephrosia sp. nov., the copper content in plant material apparently decreases as the plant dies. Thus a similar process may have taken place in the E. mucronata samples from Turkey Creek.

The analyses of E. mucronata from areas apparently devoid of mineralisation are shown in Table I9. None of the samples indicate significant enrichment in the ore-metals when expressed on the oven-dry weight basis, though several of the copper and zinc values are slightly above threshold in the case of the ppm ash figures. Moreover,

Table 18 : *Eriachne mucronata*. Analyses of Plant Samples from Turkey Creek Area, Dugald River.
Unmilled, dry-ashed material.

No	Locality	Part of Plant	% Ash	ppm of Ash			Cu/Zn Ratio	ppm of oven-dry material			ppm of soil (4-6 ins)			Cu/Zn Ratio	Rock Type
				Cu	Pb	Zn		Cu	Pb	Zn	Cu	Pb	Zn		
30/ 6539	$930^{N}/190^{W}$	Leaves & Stems	6.35	65	<25	20	3.25	4.11	<1.6	1.26	8900	<5	155	57.5	Copper stained-shales
30/ 6543	$930^{N}/180^{W}$	"	5.[illegible]5	65	<25	20	3.25	3.28	<1.25	1.01	7000	<5	140	50.0	"

Table 19 : *Eriachne mucronata* Analyses of Plant Samples from Background Areas, Dugald River.
Un-milled, dry-ashed material

No	Locality	Part of Plant	% Ash	ppm of Ash			Cu/Zn Ratio	ppm of oven-dry material			ppm of soil (4-6 ins)			Cu/Zn Ratio	Rock Type
				Cu	Pb	Zn		Cu	Pb	Zn	Cu	Pb	Zn		
40/ 160	$21{,}800^{S}/11{,}400^{W}$	Leaves & Stems	2.75	70	<10	190	0.37	1.92	<1	5.22	45	<10	120	0.37	Micaceous schists.
40/ 150	$13{,}500^{N}/100^{E}$	"	3.95	40	<10	90	0.44	1.58	<1	3.55	25	<10	30	0.83	Quartzite rubble on calc-silicates
40/ 154	$18{,}700^{N}/12{,}200^{E}$	"	3.33	75	<10	230	0.33	2.50	<1	7.66	140	<10	60	2.32	Quartzite

the soils underlying Sample 40/I60, collected from micaceous shales near the south end of the Quartzite Range, (Fig. 24), contains a slightly anomalous zinc content.

More extensive geochemical investigations have been carried out at the two other plant occurrences. The traverse made across the zone from which Sample 40/I50 was collected indicates no metal enrichment in the soils underlying the plants, (Fig. 29), and the sample contains low levels of the ore-metals. Sample 40/I54 was collected from the occurrence on the Mt.Rosebee fault line, where the geochemical results indicate relatively high copper values and smaller amounts of zinc, (Fig. 30). The plant, however, contains only slightly anomalous concentrations of these metals in the ash, while on an oven-dry weight basis both results are below threshold. Moreover, the copper:zinc ratio in the sample shows little departure from the mean background value of 0.44.

Comparison of the ore-metal contents in the plants with their concentrations in the underlying near-surface soil, (Figs. 36 and 37), indicates a similar relationship to that found in Tephrosia sp. nov. The level of zinc in the plant shows a roughly linear increase with rising soil zinc contents. As in the latter species, the points for zinc in E. mucronata show two groupings, corresponding to ranges of 25 to 600 and 3500 to 65000 ppm in the soil. Again the groupings are probably related to the sites occupied by

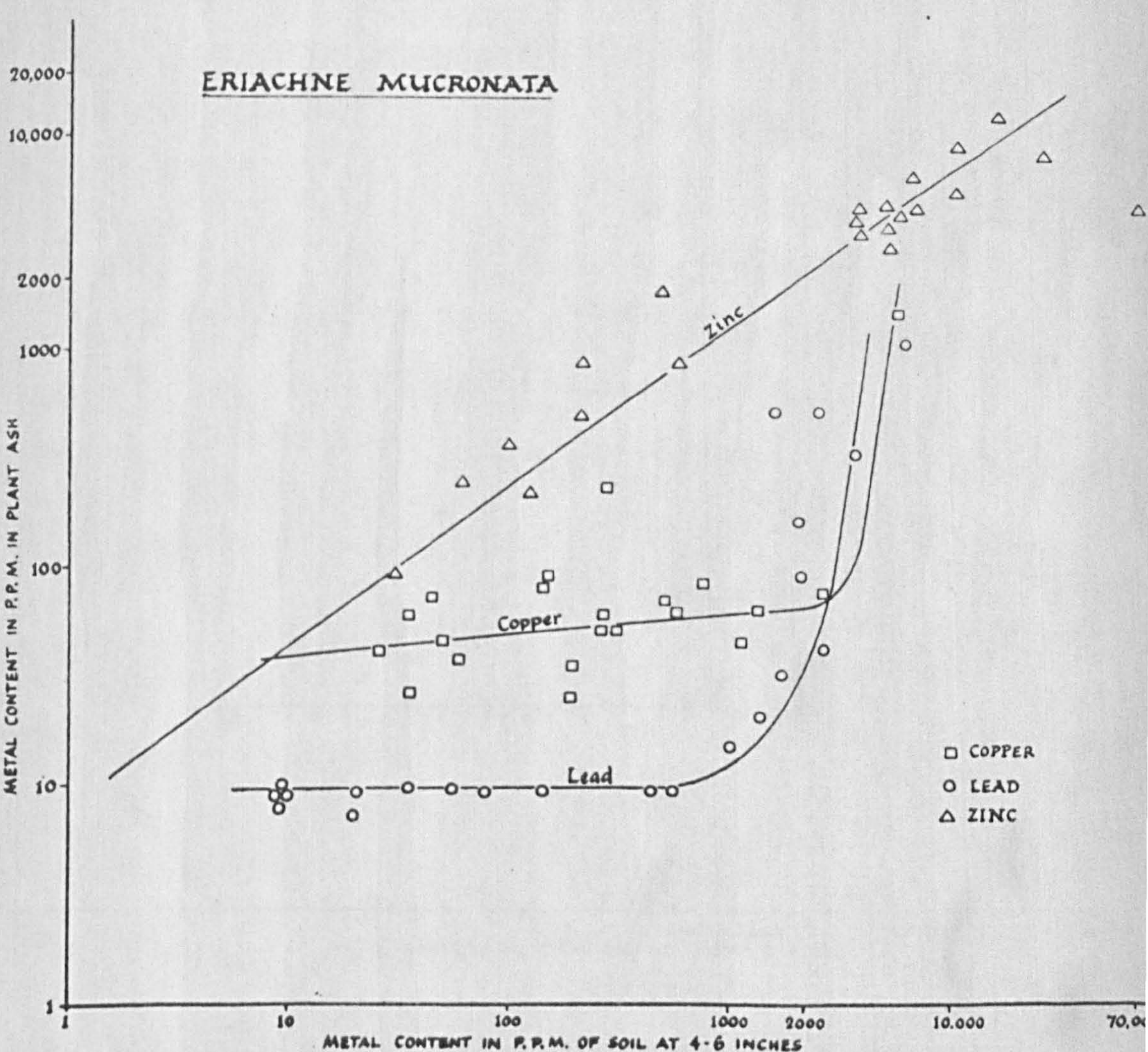


Fig. 36 Graph of Cu, Pb and Zn Content in the Ash of Leaves + Stems of <u>Eriachne mucronata</u> against the Cu, Pb and Zn Content in the Soil at 4-6 ins. underlying the sampled Plants

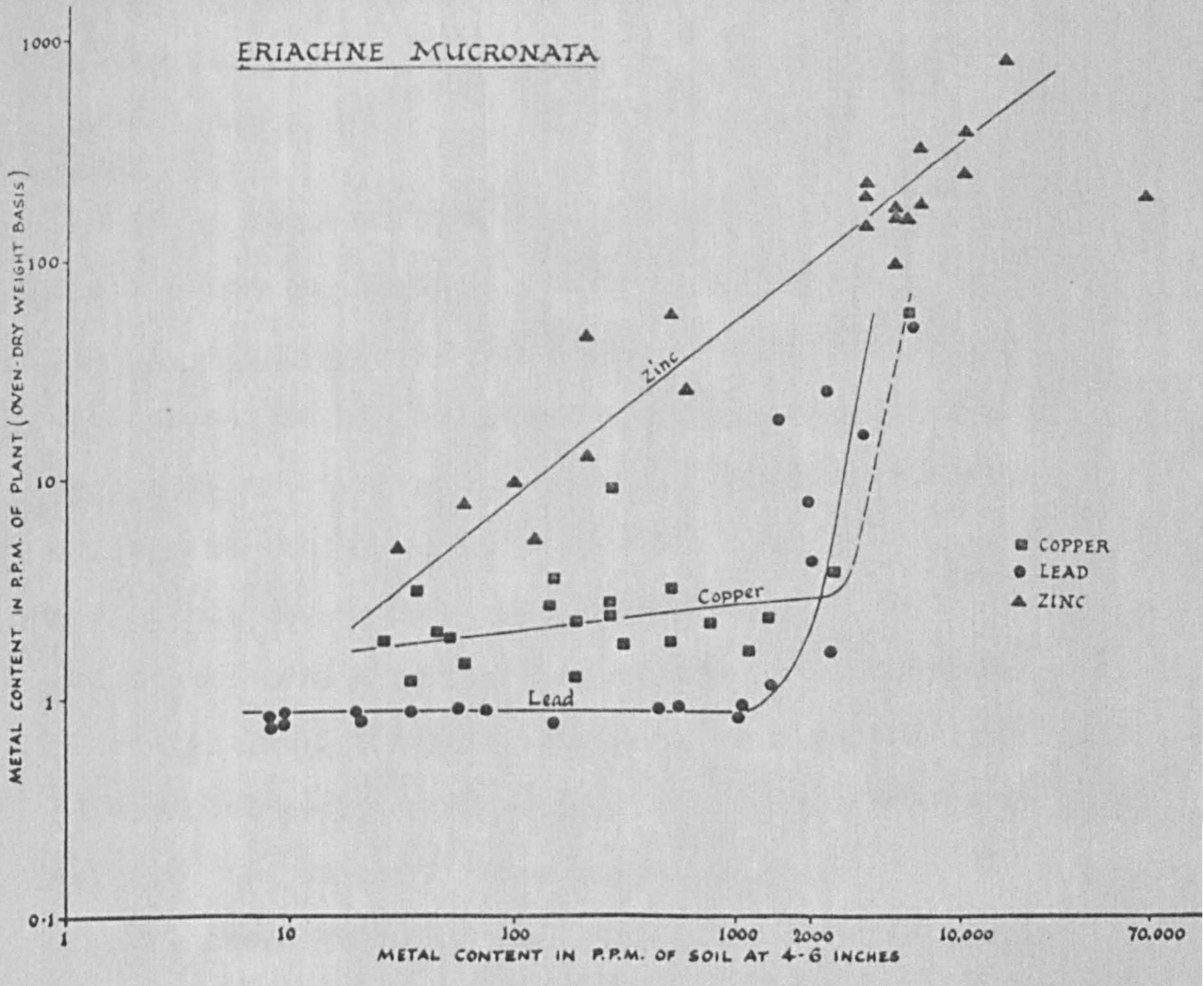


Fig. 37 Graph of Cu, Pb and Zn Content in oven-dry Leaves + Stems of *Eriachne mucronata* against the Cu, Pb and Zn Content in the Soil at 4-6 ins. underlying the sampled Plants

the species. Both the copper and lead curves indicate marked inflections. In the case of the former the inflection occurs at a soil copper content of 3000 ppm, whereas in the latter it takes place at a concentration of 1500 ppm lead in the soil.

Discussion

It is apparent from its geographical range, and from the geochemical results indicated in Tables 17 and 18, that E. mucronata can withstand extremely high levels of the ore-metals in the underlying soil. In comparison to Tephrosia sp. nov. and P. glabra, however, the plant shows a lower degree of zinc enrichment, though copper and lead can attain relatively high concentrations. With the exception of the sample situated directly above the zone of copper mineralisation, however, the Lode Area samples generally contain below-threshold copper contents, whereas in Tephrosia sp. nov. the majority were anomalous.

The lower tenor of the copper and zinc enrichment in the species may be related to the fact that it is a semi-perennial, while both Tephrosia sp. nov. and P. glabra are perennial species. Hence the material sampled in the first species will be of younger age than that collected from the perennial plants. Assuming the same rate of metal uptake by all three, it is apparent that the greater age of the material sampled in the perennial species will allow a higher degree of metal enrichment.

Comparison of the results obtained from the analyses of T. pungens shows that E. mucronata may contain appreciably higher quantities of the ore-metals. In the case of zinc, however, the metal content in the plant ash does not exceed the level in the near-surface soils underlying the sampled plants, and in this respect the two species are similar. The aerial parts of T. pungens are relatively short-lived also, growth being renewed each year while the older material dies off. Again, therefore, the aerial parts of this species will be of comparatively young age.

The inflections in the curves of the copper and lead contents in the plant compared with that in the underlying soil ~~occurs~~ occur at a higher concentration in the soil in this species than in T. pungens or Tephrosia sp. nov. This suggests that E. mucronata can withstand higher concentrations of lead and copper in the rooting medium than the other species, a suggestion borne out by their distribution in the field.

The geochemical investigations indicate that the distribution of this species in areas devoid of mineralisation, may, in certain cases, be related to anomalous concentrations of copper and zinc in the underlying soil. Analyses of the plant from these areas gave relatively low values for the ore-metals, however. In this respect, E. mucronata resembles Tephrosia sp. nov., where again specimens from this type of occurrence showed little significant enrichment in the ore-metals, particularly in the case of copper. While occurrences of both these species in areas not known to be mineralised may indicate metal enrichment in the substrate, therefore, a better estimate of the tenor and character of this enrichment is gained from soil analyses. Nevertheless, by pinpointing the site of these favourable zones, the species could be of considerable value in narrowing the scope of geochemical prospecting.

(f) Biogeochemistry of Bulbostylis barbata

In view of its relatively sparse distribution, both in the vicinity of the ore-deposits and in un-mineralised areas, relatively few samples of this small sedge have been analysed. The results of the analyses, all on specimens collected in the Lode Area, are shown in Table 20. The most striking feature of the values is the extremely high tenor of zinc in the plants, even though the available geochemical results indicate low values for this metal in the associated soils. Lead is also present in anomalous quantities in all samples, while, again in spite of the relatively low levels in the underlying soils, all the samples contain above threshold concentrations of copper.

It is of interest to note that the stems of each sample contain lower concentrations of the ore-metals, when expressed on the oven-dry weight basis, than the corresponding leaves or flowers. In the two samples where leaves have been analysed, this organ gave the highest value for

Table 20: <u>Bulbostylis Barbata.</u> Analyses of Plant Samples from Dugald River Lode Area.
Un-milled, dry-ashed material.

No.	Locality	Part of Plant	% Ash	ppm of Ash			Cu/Zn Ratio	ppm of oven-dry material			ppm of soil (4-6 ins)			Cu/Zn Ratio	Rock Type
				Cu	Pb	Zn		Cu	Pb	Zn	Cu	Pb	Zn		
40/75	1400 S/W / 240 W	Flowers	6.02	230	30	13,500	0.017	13.86	1.81	813					Footwall shales.
		Leaves	6.79	125	62.5	13,000	0.009	8.50	4.25	883					
		Stems	1.83	160	<20	19,000	0.008	2.92	<1	347					
40/82	460 S/W / 340 W	Flowers	5.36	120	80	12,000	0.01	6.43	4.28	643	150	415	1440	0.104	Alluvium on Lode/footwall junction
		Stems	1.79	130	160	14,000	0.009	2.32	2.86	250					
40/88	370 N/W / 390 W	Flowers	5.08	230	320	9,000	0.025	11.68	16.25	457	140	1300	2100	0.066	Shales
		Stems	1.97	90	470	13,000	0.007	1.77	9.25	256					
40/111	4800 N/W / 1120 W	Flowers	5.15	425	<50	23,000	0.018	21.88	<2.57	1184					Hangingwall shales
		Leaves	3.74	150	50	17,000	0.009	5.61	1.87	635					
		Stems	2.07	135	15	24,000	0.005	2.79	0.31	496					

lead, and in one case for zinc, while the maximum values for copper occurs in the flowers.

Discussion

The extremely high zinc enrichment found in the samples of B. barbata is particularly noteworthy in view of the fact that the species is an annual. In E. mucronata and T. pungens, where the aerial parts sampled are again of comparatively young age, the level of zinc in the plant ash did not exceed that in the underlying soil, while in B. barbata the former value is many times higher.

The distribution of this species indicates that it can withstand extremely high concentrations of the ore-metals in the rooting medium. It therefore seems possible that its apparent ability to absorb large amounts of the ore-metals without obvious injury may serve as an adaptive mechanism towards these conditions. In this respect it resembles the perennial species P. glabra and Tephrosia sp. nov. which were also apparently able to assimilate large quantities.

(g) Biogeochemistry of Fimbristylis sp. (Dugald R. MMC/ DMJP No. 279)

As in B. barbata, difficulties were encountered in collecting sufficient material of this small sedge from one locality to allow separate analyses of the flowers, leaves and stems.

The species has a relatively sparse distribution, the greatest concentration occurring near the malachite-stained shales at the southern end of the Lode outcrop. The plant samples from this zone, (Table 2I), all contain concentrations of copper which are above the threshold level, but the enrichment is not marked in comparison to the level in t underlying soils. In keeping with the low tenor of lead in the soils of this area, only one sample contains detectable amounts of this metal. Similarly, although present in anomalous quantities, the concentration of zinc in both plants and soils is relatively low compared with other species collected from the Lode Area.

Sample 40/I5 was collected from the only occurrence of the species observed outwith the immediate vicinity of the Lode, on argillaceous limestones near the north end of the Lode Area, (Fig. 3C). Fimbryitylis sp. may here be associated with a minor zinc anomaly, (Fig. 5), but the plant shows little enrichment in this element.

Discussion

This species bears a certain resemblance to B. barbata, but the two sedges may be distinquished by the fact that Fimbristylis sp. has more recurved stalks. It is of interest to note that, where separate analyses were performed on the various aerial parts, the distribution of the ore-metals within the two species is also similar. In both there is a tendency for the flowers to show a

Table 21 : *Fimbristylis* sp. (Dugald River MMC/DMJP No. 279). Analyses of Plant Samples from Dugald River Lode Area. Un-milled, dry-ashed material.

No.	Locality	Part of Plant	% Ash	ppm of Ash			Cu/Zn Ratio	ppm of oven-dry material			ppm of soil (4-6 ins)			Cu/Zn Ratio	Rock Type
				Cu	Pb	Zn		Cu	Pb	Zn	Cu	Pb	Zn		
40/13	$1600^{S}_{W}/550$	Leaves & stems	7.51	87.5	<5	960	0,091	6.57	<1	72.09	1100	20	600	1,83	Shales
40/126	$1600^{S}_{W}/300$	Leaves & stems	6.31	140	<10	400	0.35	8,83	<1	25.24	1500	<25	230	6.52	Hangingwall shales
		Flowers	4.27	390	55	670	0;58	16;65	2.34	28.60					
40/132	$1440^{S}_{W}/400$	Leaves	9.58	70	<10	220	0.32	6.70	<1	21,07	775	<25	120	6.45	Shales
		Stems	4.28	135	<10	400	0.34	5,77	<1	17.12					
40/125	$1300^{S}_{W}/260$	Leaves & stems	12.41	115	35	1700	0.068	14,27	4.34	210,9					Lode/hanging-wall junction
40/15	$6500^{N}_{W}/350$	Leaves & stems	7.34	27.5	<10	180	0.15	2.02	<1	13,21	60	12.5	160	0.37	Argillaceous limestones

greater degree of enrichment that either the leaves or stems. Although further sampling would be required to confirm this, it seems possible that variation in metal distribution within the aerial parts of plants may be less marked between two species from the same family than between species from different families.

The precise status of this species as regards its association with mineralised deposits is difficult to determine. Although comparatively abundant in the vicinity of the copper-bearing hangingwall shales at the southern end of the Lode, (Fig. 3C), the species was not found in other regions of copper mineralisation. While showing a higher degree of metal enrichment than samples of T. pungens from the Lode Area, (Table II), the enrichment is less marked than in the other species associated with mineralisation. In this respect, therefore, it occupies a rather intermediate position.

(h) Miscellaneous species

Eight samples of miscellaneous species, some of which possibly are associated with mineralisation, have been analysed and the results expressed in Table 22.

The sample of Triodia longiceps (Sample 40/I37) was collected from the hangingwall shales near the southern extremity of the Lode outcrop, where the species is quite abundant, (Fig. 3C). Since the grass was sterile at the time of collection, only the leaves were analysed. These

Table 22: Miscellaneous species. Analyses of Plant Samples from the Dugald River Area. Un-milled, dry-ashed material.

No.	Species	Locality	Part of Plant	% Ash	ppm of ash Cu	ppm of ash Pb	ppm of ash Zn	Cu/Zn Ratio	ppm of oven-dry material Cu	ppm of oven-dry material Pb	ppm of oven-dry material Zn	ppm of soil 4-6 ins Cu	ppm of soil 4-6 ins Pb	ppm of soil 4-6 ins Zn	Cu/Zn Ratio	Rock Type.
40/137	Triodia longiceps	1143$^{S}_{W}$/305	Leaves	3.17	165	<10	4400	0,037	5.23	<1	139.5	2700	55	220	12.27	Hangingwall shales
40/5	Scaevola densivcstita	4320$^{N}_{W}$/1400	Leaves & stems		100	<25	150	0,67								Calc-silicates
40/7	Scaevola densivestita	39,200$^{N}_{W}$/2370	Leaves & stems		425	<25	120	3.54				850	15	40	21.25	Fragmental calc-silicates
40/166	Cassia desolata	21,500$^{N}_{W}$/1000	Leaves	8.40	70	<10	170	0.41	5.88	<1	14.28					Sheet wash cover
			Stems	7.18	90	<10	120	0.75	6.46	<1	8.61					
40/8	Cassia desolata	24,650$^{N}_{W}$/1100	Leaves	10.25	80	<10	220	0.36	8.20	1.02	22.54	135	10	50	2.70	Sheet wash cover
			Stems	8.31	150	<10	120	1.25	12.46	<1	9.97		(18 in depth.)			
40/153	Ptilotus obovatus	38,800$^{N}_{E}$/2870	Flowers	15.10	250	<20	200	1.25	37.7	1.51	30.2		Not analysed for Pb and Zn but levels low in this area.			Fragmental calc-silicates
			Leaves	18.10	100	<10	60	1.66	18.1	1.81	10.86	100				
			Stems	7.82	90	<10	60	1.50	7.03	<1	4.69					
40/128	Ptilotus obovatus	Pit for Copper at Block 14, Cloncurry	Flowers	8.82	1300	20	260	5.0	114.66	1.70	22.93					Copperstained calc-silicates
			Leaves	21.0	350	<10	210	6.8	283.5	2.1	44.10					
			Stems	8.82	1400	20	280	5.0	123.48	1.70	24.69					
40/17	Borreria australiana	500$^{N}_{W}$/1100 Turkey Creek	Flowers	7.76	80	<10	190	0.42	6.20	<1	14.74					Calc-silicates
			Leaves	12.00	80	<10	150	0.53	9.60	<1	18.00	15	10	10	1.5	
			Stems	6.06	75	<10	120	0.62	4.54	<1	7.27					

threshold quantites of zinc, though lead is at the lower limit of detection in all parts. The copper:zinc ratios in the stems are both well above the mean background value of 0.44.

Sample 40/8 was collected from the vicinity of the eastern end of Transect I2, (Fig. IOA), where Cassia desolata is quite abundant. The soil underlying the sample contains an above-threshold copper content (I35 ppm) but, as will be evident from Fig. II, the level of copper in the soils is comparatively high throughout the greater part of this transect. The anomalous quantities of copper in the samples of Cassia desolata from this area are presumably related to the higher soil copper contents, but whether these are indicative of mineralisation in the rocks below is not known.

The low herb Ptilotus obovatus occurs sparingly on the outskirts of regions of copper mineralisation in the Dugald River Area. Sample 40/I53 was collected from the vicinity of the Little Eva copper occurrence, (Fig. 2). Both the flowers and stems contain above-threshold results for copper, though the copper content in the underlying soil is only IOO ppm. On an oven-dry weight basis, the zinc content in the flowers also exceeds the threshold level of I3 ppm. The copper:zinc ratios in both parts are considerably above the mean background value of 0.44.

A second sample (Sample 40/I28) was collected from an area of copper mineralisation near Cloncurry. The analyses indicate that the plant contains a high concentration of this metal, with the maximum value occurring in the leaves. The results for zinc are also above-threshold, and again the leaves contain the largest amount.

Borreria australiana is quite common in the Turkey Creek Area, but shows no close association with the malachite-stained shales which outcrop in this region. Notwithstanding the low level of copper in the underlying soil, analyses of the flowers, leaves and stems of the plant yielded results for copper slightly above the threshold value of 70 (4) ppm. On an oven-dry basis, the leaves and stems also contain above-threshold concentrations of zinc.

(i) Results of plant analysis for copper, lead and zinc, and trace element analysis of plants and soils on traverse at 100 N, Dugald River Lode

In order to investigate more closely the variations in metal content occurring in the plants and soils in the vicinity of lead-zinc mineralisation, a short traverse was made across the Lode and host shales at 100 N, (Fig. 4C). Samples of the leaves of T. pungens, the leaves and stems together of E. mucronata, and the soil (-80 mesh) at 2 to 6 inches were collected. The 00 point of the traverse was sited at the boundary between the area dominated by T. pungens and the Lode assemblage, where E. mucronata is the most abundant species. At this point, samples of both species were collected, (designated by T and E respectively

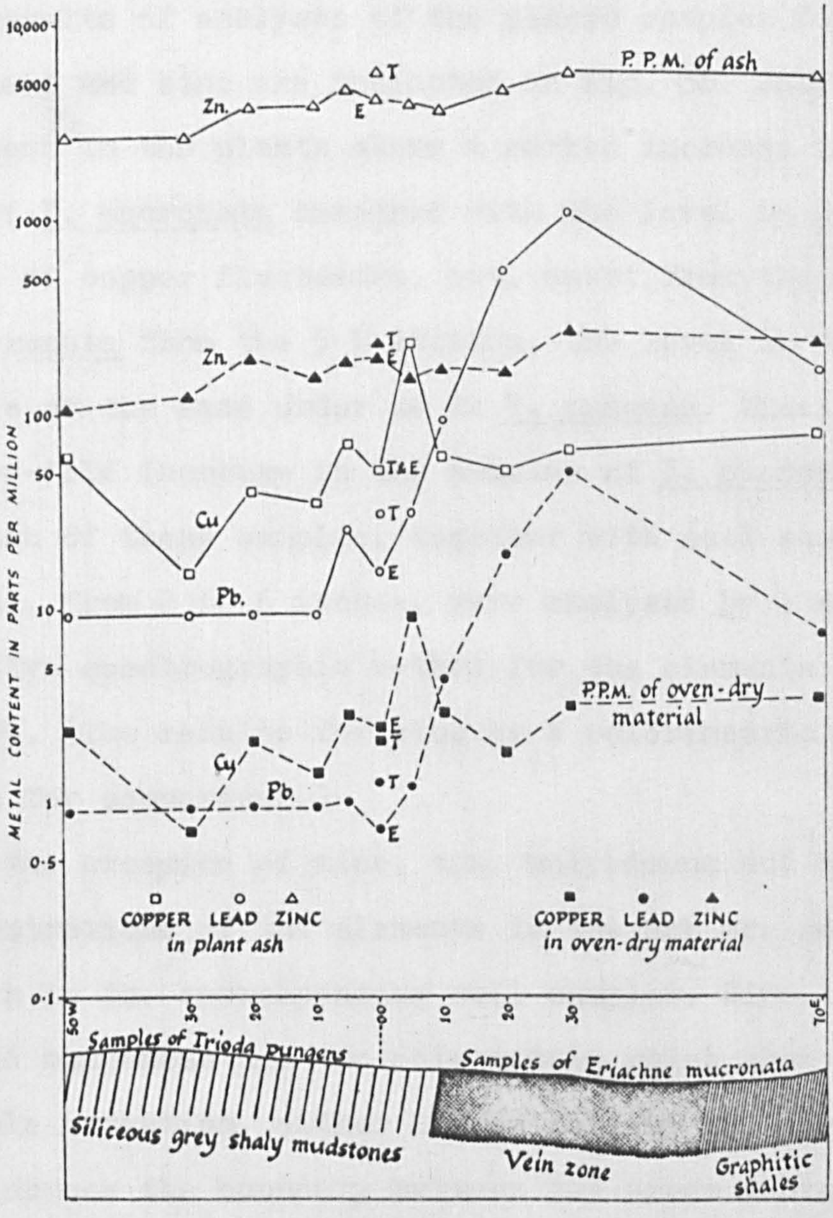


Fig. 38 Results of Analyses of <u>Triodia pungens</u> (leaves) and <u>Eriachne mucronata</u> (leaves + stems) for Cu, Pb and Zn on 100 N Traverse, Dugald River Lode

on the graphs); further west the former species was sampled, while to the east samples of _E. mucronata_ were taken.

The results of analyses of the plants samples for copper, lead and zinc are indicated in Fig. 38. Only the lead content in the plants shows a marked increase in the samples of _E. mucronata_ compared with the level in _T. pungens_. The level of copper fluctuates, but, apart from the sample of _E. mucronata_ from the 5 E station, the level in this species is of the same order as in _T. pungens_. Zinc shows only a two-fold increase in the samples of _E. mucronata_.

The ash of these samples, together with soil samples, (-80 mesh), from 2 to 6 inches, were analysed by a semi-quantitative spectrographic method for the elements indicated in Fig. 39. (The results for zinc by a colorimetric method are shown for comparison.)

With the exception of zinc, tin, molybdenum and bismuth, the concentrations of the elements in the ash are generally lower than in the corresponding soil samples. Zinc, lead, silver and manganese are the only metals which show an appreciable variation, either in the soil or the plant samples, across the boundary between the areas dominated by _T. pungens_ to the west and the _E. mucronata_ zone.

The level of zinc in the plants shows only a small increase in the samples of _E. mucronata_, even though the concentration of this metal increases markedly in the underlying soil. The level in the soil rises from I200 ppm

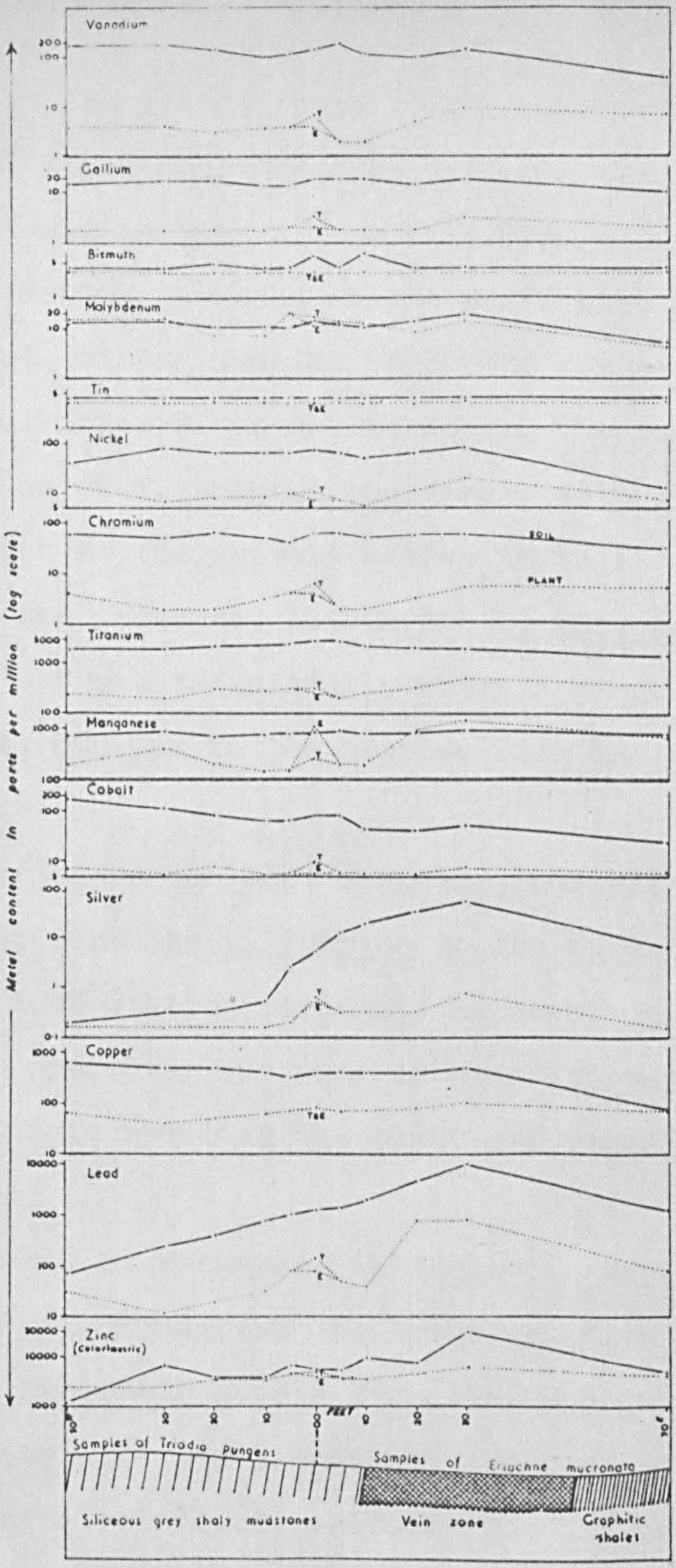


Fig. 39 Results of Spectrographic Analyses of Triodia pungens (leaves) and Eriachne mucronata (leaves + stems) on 100 N Traverse, Dugald River Lode

at the western extremity to 30,000 ppm over the centre of the Lode, while over the same distance the concentration in the plant ash increases from only 2600 ppm to 5500 ppm.

The results for lead in the soils show an even greater enrichment, rising from 80 to 10,000 ppm over the same horizontal interval as quoted above. The lead content in the samples of T. pungens increases, with some fluctuations, from 30 ppm at the western extremity to 150 ppm at the 00 point of the traverse. Within the E. mucronata zone, the level in the plants initially shows a drop, then increases rapidly to 800 ppm in the samples from the 20 and 30 E stations.

Silver shows the most striking increase in the soil on traversing from the T. pungens to the E. mucronata zones. From the 10 W station to 30 E, the level increases from 0.5 to 60 ppm. Over the same interval, however, the concentration of this metal in the plant ash rises from only $<$ 0.2 to 0.7 ppm.

The level of manganese in the soil samples is level at about 850 ppm throughout the traverse. With the exception of the E. mucronata sample from the 00 point, where the ash contains 1200 ppm manganese, the concentration in the plant remains relatively uniform from the western extremity of the traverse to 10 E. From this point eastwards, however, the level in the plant increases rapidly, reaching 1500 ppm in the sample of E. mucronata from 30 E.

Discussion

It is apparent that of the elements analysed, only zinc, lead, silver and manganese show appreciable variation, either in the soil or plant samples, across the boundary between the Triodia pungens and Eriachne mucronata zones.

The reason for the high level of manganese in the samples of E. mucronata from the Lode zone and footwall is unclear, since the metal shows no corresponding increase in the underlying soils. However, Stiles (1958) notes that the adsorption of manganese, and the development of symptoms of this element, may be influenced by the presence of other substances, in particular of compounds of iron in the rooting medium. Since the Lode itself is rich in iron sulphides, (P. 46), it is possible that the increased uptake of manganese by E. mucronata is due to excess of the former element in the soils over the Lode.

Of the analysed elements, it is evident that the presence of abnormal quantities of zinc, lead and silver is the main distinction between the soils with E. mucronata and those with T. pungens. It would seem, therefore, that the position of the boundary between these two vegetation types is largely determined by the distribution and concentrations of these metals within the underlying soils. Of the three silver shows the largest increase across the boundary, so it is possible that the presence of this element in excess is the most important single factor distinguishing the soils of the E. mucronata zone from those of T. pungens. However, it seems more probable that the presence of toxic concentrations of zinc, lead and silver is the explanation of the "cut-out" of T. pungens and its replacement by E. mucronata. This species is apparently able to withstand these highly toxic conditions, possibly by better adaptation to absorption of larger quantities of zinc, lead and silver than the more widespread species, such as T. pungens.

It is of interest that, with the exception of manganese, the sample of T. pungens collected from the 00 point generally contained higher concentrations of the elements analysed than the sample of E. mucronata from the same station. While this may indicate increased absorption of trace elements by the former species at this locality, the difference is more probably related to differences in the age of the material sampled, or to a more advanced stage of senescence in E. mucronata. Rankama and Sahama, (1949), point out that the content of most of the minor elements decreases in plants as they wither and die, and it was noted that, at the time of collection, withering was more advanced in E. mucronata than in T. pungens.

(3) Discussion on inflections in the curves of metal content in the plants against the soil metal content.

In the discussion on the results of analyses of Tephrosia sp. nov., Eriachne mucronata and Triodia pungens, reference was made to prominent inflections which occurred in the curves of the metal content in the plants plotted against the metal content in the underlying near-surface soils.

These inflections were noted in the curves for lead and copper in all three species, though in the case of the coppe curve in <u>T. pungens</u> the change in slope was less abrupt than in the other species. The curves are concave upwards. Thus, below the point of inflection the increase in the tenor of copper and lead in the plant lags behind that in the underlying soil, while above the inflection the plant content rises rapidly over a comparatively small increase in the soil.

In contrast, the curve for zinc in all cases indicated a straight line relationship; i.e., the level of zinc in the plants increased more or less constantly with increase in the concentration of this metal in the underlying soils.

As regards copper, these observations disagree with those by Lundblad et al, (1949). In an experimental investigation of copper deficiency in the peat soils of northern Sweden, and in the sandy and other light soils of the south, these authors found that the mean copper content of the plants increased rapidly up to a soil value of about 15 kg/ha for peat soils and 20 kg/ha for mineral soils. Above these levels, the increase in plant copper content did not reflect the increasing copper content of the underlying soil to the same extent as at the lower concentrations of copper in the soils.

As indicated in Table 23, the co-ordinates on the graphs at which the inflections take place differ from species to species.

Table 23: Co-ordinates for Inflections in the Curves of Copper and Lead Content in Plants against the Copper and Lead Content in the underlying Soils.

Species	Copper		Lead	
	ppm Soil	ppm Plant	ppm Soil	ppm Plant
Tephrosia sp. nov., leaves	1000	150 (12)	1000	<10 (<1)
stems		150 (6)		<10 (<1)
E. mucronata (leaves + stems)	3000	70 (3)	1500	<10 (<1)
T. pungens (leaves)	-	-	600	<10 (<1)

The observed increase in rate of copper uptake by the plant occurs at a higher level in the soil in the case of E. mucronata than in Tephrosia sp. nov. On the other hand, the level of copper in the plant shows the reverse relationship; i.e., the inflection takes place at a lower plant copper content in the former species than in Tephrosia sp. nov. This may suggest that, while Tephrosia sp. nov. can absorb a larger quantity of copper than E. mucronata, the latter species can withstand higher concentrations in the soil. This agrees with their geographical distribution and the maximum copper contents found in the soils associated with the two species; i.e., 8900 ppm in the case of E. mucronata as against 1800 ppm in *Tephrosia* sp. nov., (Tables 14, 18).

The inflection in the curves of lead content in the plants against the soil lead contents, (Table 23), occur at the lower limit of detection; i.e. < 10, (< 1) ppm in *Tephrosia* sp. nov., *E. mucronata* and *T. pungens*. However, the level of lead in the soil at which the observed increa in the rate of uptake takes place varies from species to species. It occurs at a soil lead content of 1500 ppm in *E. mucronata*, at 1000 ppm in *Tephrosia* sp. nov., and at 600 ppm in *T. pungens*. This may suggest that *E. mucronata* is able to withstand higher lead concentrations than *Tephrosia* sp. nov., which in turn is able to grow in soils richer in this element than *T. pungens*. As in the case of copper, this agrees with their geographical distribution and with the maximum lead contents in the soils underlying the three species; i.e., 6000 ppm in the case of *E. mucronata*, 1300 ppm in *Tephrosia* sp. nov. and 1200 ppm in *T. pungens*.

Three possible explanations for these inflections are put forward, but it is emphasised that much experimental work would be required to elucidate the precise reason.

A. Uptake of copper and lead is inhibited by the plants up to the concentration in the soil corresponding to the point of inflection; above this level, some kind of physiological barrier is broken and the metal is allowed to pass freely into the plant.

As far as is known, however, no evidence has yet been presented indicating the operation of such a mechanism. In fact, the work of Lundblad et al, (ibid), suggests that the reverse may be the case and suppression of metal uptake may occur at the higher levels of soil metal content.

B. The mobility of the metals has been affected by changes in soil pH. It is well known that copper, for example, is markedly less mobile under conditions of very high or very low pH. Hence, a plant growing in calcareous soils might be expected to absorb less copper than a plant of the same species from a neutral or slightly acid soil.

However, the majority of plant samples were collected from the mineralised outcrops, from the shales bordering the Lode, from quartzite alluvium of from arid red earth soils. Reference to Table 4 indicates that the pH of samples of surface soil from these areas ranges from only 5.6 to 6.9. It seems unlikely, therefore, that soil pH can have caused the marked variations in the rate of copper and lead uptake indicated by the graphs.

C. A separate strain of the species Tephrosia sp. nov. and E. mucronata has been evolved which is capable of absorbing higher concentrations of copper and lead than the species population occurring on soils low in these metals. Although no marked inflection in the curve for copper is evident in the case of T. pungens, the curve of lead content in the plant against the soil lead content shows a similar inflecti to those in Tephrosia sp. nov. and E. mucronata. It is therefore possible that T. pungens has evolved an ecotype, capable of existing under conditions of relatively high soil lead content.

In the writer's opinion, the last explanation is the most likely, since ecotypes of this kind have been reported for several annual herbs growing on soils derived from serpentinite in California, (Krukkeberg, 1951, 1954), and also for a population of Agrostis tenuis growing over a disused lead mine in North Wales, (Bradshaw, 1952).

Soil analyses have shown that these serpentine soils are high in magnesium, chromium and nickel, and deficient in calcium, nitrogen, phosphorus and occasionally molybdenum. Although chiefly restricted to serpentine, strains of Streptanthus glandulosus are occasionally also found in non-serpentine areas. When grown in experimental cultures, collections of strains from non-serpentine localities showed a marked intolerance to serpentine soils, while collections of other strains from serpentine sites attained normal growth on serpentine soils.

Experimental results show that serpentine plants may be restricted to serpentine by intolerance of the more rigorous competition in non-serpentine plant communities. Edaphic factors are also important, however, since tests have shown that tolerance of the low level of calcium is a principal adaptation required for growth of plants on serpentine soils

Similar results were reported by Bradshaw (ibid) in his study on _Agrostis tenuis_. One population of this grass was growing over a disused lead mine where the soils contained about 1 % lead and 0.03 % zinc, and a second from ordinary pasture where the soils were low in these metals. On cultivation in normal soils, the plants from the mine were distinctly smaller and grew more slowly than the pasture samples. On being transplanted as tillers into soil from the mine, the mine samples grew normally while the pasture samples made no growth at all, 50 % of the tillers being dead within three months. The latter plants were found to have produced mis-shapen roots rarely more than 2 mm. in length, while the former rooted normally. There was no indication of any change in resistance with time, since similar results were obtained after the material had been in cultivation in normal soil for two years.

It is evident that separate ecotypes, of the type postulated for _Tephrosia_ sp. nov. and _E. mucronata_, can exist in nature. Although culture experiments of the type reported above would be required to confirm this, intraspecific variation would seem to offer a reasonable explanation of the variations in the rate of copper and lead uptake evident in these species. It is possible that _T. pungens_ has also produced a separate strain which is capable of absorbing higher quantities of lead than the more widespread strains which occur on normal soils.

The fact that zinc seems to pass freely into the plant at all levels of soil zinc content, and that the overall level of this element in the plants is higher than copper or lead, may suggest that zinc is the least toxic of the three metals.

Although insufficient analytical data is available for Polycarpaea glabra, Bulbostylis barbata and Fimbristylis sp., it is possible that these species also have evolved separate ecotypes capable of surviving on soils containing toxic metal concentrations.

Intraspecific variation may also serve as a possible explanation of the distribution patterns of the species associated with mineralisation. All of these plants may occur both in the vicinity of ore-deposits and, though less frequently, in areas where mineralisation is unknown. Most plants occurring in the Dugald River Area are restricted to a relatively narrow range of habitats; e.g., Astrebla pectinata to heavy clay soils, Sporobolus australasicus to sandy or loamy soils. It is evident from the variation in the vegetative cover over the ore-deposits that the presence of toxic quantites of copper, lead and zinc in the soils have a powerful influence on vegetation distribution. One might therefore expect that, if only species population were in question, the plants occurring over the ore-deposits would be restricted to these areas. Since this is not the case, and if this postulate is correct, it follows that two separate populations, one adapted to growing under toxic conditions, have been evolved in the plants which are associated with mineralisation.

(4). Definition of biogeochemical anomalies.

In some previous investigations, e.g., those by White, (1950), and Worthington, (1955), it was reported that biogeochemical anomalies associated with copper or lead-zinc mineralisation are better defined by using the ratio of copper to zinc in the plant samples, rather than by the absolute copper and zinc contents alone. The assumption is that, while the copper and zinc contents in plants may vary from species to species, the ratio of these two metals in plant material will show a smaller variation, unless influenced by the presence of anomalous quantities of these metals in the rooting medium.

To test this hypothesis, the mean copper:zinc ratios for the plant samples, (all parts), collected in the vicinity of copper and lead-zinc mineralisation in the Dugald River area have been compared with the mean copper:zinc ratio in the samples of Triodia pungens collected from the Background Traverse, (Table 24).

Table 24: Comparison of Cu:Zn Ratios in Plant Samples, (all parts), from Lode Area, Turkey Creek and Background.

	Mean Cu:Zn Ratio	Stand. Devn	Range
Lode Area. (88 determinations).	0.057	0.1003	0.0020 - 0.58
Turkey Creek Area (22 determinations).	2.77	2.25	0.60 - 9.16
Background. (16 determinations).	0.44	0.21	0.19 - 0.87

Note: - Samples 40/138 and 139 were ignored in the calculation of the mean for the Lode Area; these were situated on a copper vein which is atypical of the mineralisation of this area as a whole.

The above results were submitted to a "Student's t test", (Moroney, 1957). The difference between the mean of the samples from the Lode Area and the mean background value gave a value for t of 6.135, which is statistically highly significant. Similarly, the difference between the mean copper:zinc ratio for the plant samples from Turkey Creek and the mean background value gave a value for t of 4.829, which again is highly significant.

Although the ranges in the three groups of samples overlap, therefore, it would appear that variations in the copper:zinc ratio in the plant are closely related to the presence of copper and zinc mineralisation at depth.

These findings were compared with those using the absolute metal contents in the plants alone. The results of plant analyses for lead and zinc in the Lode Area, (including all aerial parts of the plants), are summarised in Table 25, and the results for copper in samples from the Turkey Creek Area in Table 26.

Table 25: Mean, Range, Ratio of Mean Anomalous:Threshold Value and Percentage of Results above Threshold Value for Lead and Zinc in Plant Samples, (all parts), from Lode Area.

Metal	Mean	Range	Ratio of Mean Anomalous to Threshold Value (approximate)	% Result >Thres hold
Lead - ppm Ash	80	<10-1050	4:1	34%
Lead - ppm oven-dry material	3.5	< 1-49.67	1.7:1	25%
Zinc - ppm Ash.	7320	220-42,000	33:1	97%
Zinc - ppm oven-dry material	312	10-1943	24:1	96%

Table 26: Mean, Range, Ratio of Mean Anomalous:Threshold Value and Percentage of Results above Threshold Value for Copper in Plant Samples, (all parts), from Turkey Creek Area.

	Mean	Range	Ratio of Mean Anomalous to Threshold Value (approximate)	% Result Thresho
Copper - ppm Ash	425	65-1300	6:1	91%
Copper - ppm oven-dry material	19.9	3.21-73.25	5:1	91%

While the ratios of the mean copper content to the threshold value in the plant samples from the Turkey Creek Area are less than the corresponding values for zinc from the Lode Area, it is evident that the percentage of results for copper above the threshold level compares favourably with the results for zinc from samples from the Lode Area.

In view of the high percentage of plant samples containing above-threshold levels of ore-metal from areas of copper and zinc mineralisation, it would seem that little advantage is to be gäined by using the copper:zinc ratios in plants as a means of defining mineralisation rather than the levels of copper and zinc in the plants alone.

If the former method were used in this region, the writer would suggest that, assuming a reasonable number of plant samples, a mean copper:zinc ratio below 0.1 should be considered anomalous for zinc, and one above 1.0 anomalous for copper. These figures contrast with those quoted by Warren and Delavault, (1949), who state that a mean copper:zinc ratio below 0.07 should be considered anomalous for zinc, and one above 0.23 anomalous for copper.

As regards the lead content in plants, only 34% (25% on an oven-dry weight basis) of the samples from the Lode Area are above the threshold level for this metal, while the ratios of the mean anomalous to threshold values in the ash and oven-dry material are only 4:1 and 1.7:1 respectively. It would appear, therefore, that a lead deposit is less

methods
easily detected by biogeochemical than either copper or zinc mineralisation.

(5) Conclusions

(i). Samples of herbaceous plants growing in areas remote from mineralisation in the Dugald River Area contained zinc, copper and lead, in decreasing order of abundance. The mean background values, based on sixteen samples of the leaves of the grass, Triodia pungens, collected along a traverse following the Mt. Isa - Cloncurry road were :- for copper 44 (2.42) ppm, for lead $<$10 ($<$1) ppm, and for zinc 119.3 (6.52) ppm. The mean copper-zinc ratio in these samples was 0.44.

(ii). The threshold level in plants, (defined as the mean background value plus twice the standard deviation from the mean), were as follows :- for copper 70 (4) ppm, for lead 20 (2) ppm, and for zinc 220 (13) ppm.

(iii). Analysis of plant samples from areas of copper and lead-zinc mineralisation indicated that plants absorbed appreciable quantities of these metals when present in abnormal amounts in the rooting medium.

(iv). Uptake of copper, lead and zinc varied from one plant species to another. On the evidence provided by the shrub, Tephrosia sp. nov. (Dugald River MMC/DMJP No. 5), and the perennial herb, Polycarpaea glabra, it would appear that perennial plants generally absorbed higher quantities of these metals than the semi-perennial species, such as _Eriachne mucronata_. The annual sedge, _Bulbostylis barbata_, is exceptional, in that it contains comparatively high amounts of copper, lead and zinc even when growing in soils relatively poor in these elements. The other annual sedge sampled, _Fimbristylis_ sp. (Dugald River MMC/DMJP No. 279), however, shows no decided metal enrichment.

(v). The distribution of copper, lead and zinc within the aerial parts of the plants varied from species to species and according to the metal in question. In _Tephrosia_ sp. nov., the maximum values for copper and zinc, on an oven-dry weight basis, occurred in the leaves, and the lead maximum in the stems. Samples of the flowers and fruit of this species contained relatively high copper and zinc contents in plants growing on soils poor in these metals, but in plant from the vicinity of mineralisation these parts contained low amounts of ore-metal. In _P. glabra_, the highest copper content was found in the stems, that for lead in the flowers and the zinc maximum in the leaves. The maximum values for all three metals in _B. barbata_ occurred in the flowers. In the one sample of _Fimbristylis_ sp. where separation of the flowers, leaves and stems was possible, the highest values for all three metals occurred in the flowers.

(vi). The analysis of samples of _Tephrosia_ sp. nov. from areas not known to be mineralised indicated that, in at least one occurrence, the sample contained above-threshold quantities of zinc, and the underlying soils also contained slightly anomalous concentrations of this metal. In a second occurrence, the plant marked the site of a minor copper anomaly in the underlying soil, but the level of this metal in the plants was not markedly above the threshold level. These anomalous values may indicate mineralisation at depth, but this point requires further investigation.

(vii). In two out of the three samples of Eriachne mucronata collected in areas which were apparently devoid of mineralisation, the level of zinc in the plant ash was at or near the threshold level, while one sample gave above-threshold results for copper. Moreover, one sample was collected from soils containing slightly anomalous quantities of copper, and a second from soils containing above-threshold concentrations of zinc. It is apparent that the occurrence of this species in areas remote from known mineralisation may indicate minor zones of copper and zinc enrichment in the soils. It is not known, however, whether these anomalous values in both plant and soil are related to mineralisation at depth.

(viii). Generally speaking, the species most frequently associated with mineralisation, i.e., Tephrosia sp. nov., Polycarpaea glabra, Eriachne mucronata and Bulbostylis barbata, showed a higher degree of enrichment in copper, lead and zinc than the more widespread Triodia pungens, even when growing in soils containing equivalent concentrations of these elements. This may suggest that the former species are adapted to survival on the metal-rich soils of the ore-deposits by ability to absorb larger amounts of metals without injury than T. pungens. Fimbristylis sp. occupied an intermediate position as regards metal enrichment, between the species occurring on the highly toxic soils, and T. pungens.

(ix). The ash of samples of Eriachne mucronata collected over lead-zinc mineralisation was appreciably higher in manganese and lead than samples of Triodia pungens from neighbouring un-mineralised shales. Zinc and silver showed a lesser degree of enrichment in the E. mucronata samples. The soils over the lead-zinc mineralisation contained larger quantities of zinc, lead and silver than the soils on the un-mineralised shales.

These facts suggest that E. mucronata is better adapted to withstand higher concentrations of zinc, lead and silver than T. pungens, possibly by adaptation to absorb larger amounts of these metals than the latter species. Of the three metals, silver shows the most marked increase across the boundary between the T. pungens and E. mucronata zones. The increased absorption of manganese by E. mucronata compared with the level in T. pungens may be related to the higher iron content of the rocks underlying the E. mucronata zone.

(x). At the higher concentrations of soil copper, the level of this metal in the plant ash was below that in the underlying near-surface soils. At the lower concentrations, however, the situation was generally reversed. The curves of the copper content in the plant against that in the underlying soil in the species Tephrosia sp. nov. and Eriachne mucronata showed marked inflections at soil copper contents of 1000 ppm and 3000 ppm respectively. This suggests that E. mucronata may be able to withstand higher concentrations of soil copper than Tephrosia sp. nov., a suggestion which is supported by their observed distribution in the vicinity of copper mineralisation. Above the inflections, the level of copper in the plant increased more rapidly than that in the underlying soil, while below the inflections the increase in the plant was at a lower rate than the increase in copper content in the underlying soil.

(xi). The concentration of lead in plant ash was generally below that in the underlying near-surface soil. In the species Tephrosia sp. nov., Eriachne mucronata and Triodia pungens, the curve of the lead content in the plants against that in the underlying soil showed prominent inflections. In Tephrosia sp. nov., the inflection takes place at a soil lead content of 1000 ppm, in E. mucronata at 1500 ppm, and in T. pungens at 600 ppm.

As in the case of copper, the inflections are concave upwards; i.e., below the inflection points the level of lead in the plants increased more slowly than that in the underlying soil, while above the inflections the reverse was the case.

The variation in the position of the inflection point may be related to different degrees of resistance to lead toxicity in the three species, E. mucronata being more resistant than Tephrosia sp. nov. which in turn can withstand higher soil lead contents than T. pungens. This is in agreement with the observed distribution of the three specie in the vicinity of lead-zinc mineralisation.

(xii). The inflections in the curves of copper and lead content in plant material against their concentration in the underlying soil in the species Tephrosia sp. nov. and Eriachne mucronata may indicate intraspecific variation. Although experimental work would be required to confirm this, it is suggested that, within these two species, separate strains have been evolved which, by their ability to absorb abnormal concentrations of copper and lead without injury, are adapted to grow on soils rich in these metals. This may serve as an explanation of the variation in the rate of metal uptake shown by the plants, and also of their distribution patterns; i.e., in the vicinity of mineralisation, and, though less frequently, in areas where the soil contains low concentrations of copper and lead.

(xiii). In Triodia pungens, the curve of the copper content in the plant against the soil copper content showed no marked inflection, but that for lead showed a similar inflection to those in the above-named species. This may suggest that T. pungens has also evolved a separate strain, capable of withstanding higher concentrations of lead than the more widespread strain which grows in soils low in this metal.

(xiv). Although insufficient analytical data is available, intraspecific variation may also explain the distribution patterns of the other species associated with mineralisation i.e., Polycarpaea glabra, Bulbostylis barbata and Fimbristylis sp. All may occur in the vicinity of ore-deposits, and also in areas devoid of mineralisation. In the case of P. glabra, however, analysis of samples from an occurrence in the Quartzite Range gave anomalous values for copper, lead and zinc, though the plants were growing in soils and stream sediments low in these metals. This may suggest that this plant, initially adapted to growing in soils containing toxic concentrations of copper, lead and zinc by its ability to accumulate these metals without injury, is now beginning to migrate into barren areas but has retained this characteristic.

(xv). In contrast to the curves for copper and lead, the curve of the plant zinc content in the species Tephrosia sp. nov., Eriachne mucronata and Triodia pungens against the concentration of this metal in the underlying near-surface soils showed a linear relationship. Thus, the zinc content in the plants increased at a constant rate with increase in the level in the soil. In the graphs of plant metal content against soil metal content in the species Tephrosia sp. nov. and Eriachne mucronata, some groupings of the points for zinc are evident. This is related to the nature of the occurrence of the two species; i.e., on the zinc-poor soil of the Turkey Creek Area and areas remote from known mineralisation, and on the zinc-rich soils of the Lode Area.

(xvi). Ninety-one percent (as regards both the copper content in the ash and in the oven-dry material) of the samples collected in the vicinity of the Turkey Creek copper occurrence contained concentrations of this metal above the threshold level. The ratio of the mean of the determinations for copper in all aerial parts of the plants from this area to the threshold level was 6:1 on a ppm ash basis and 5:1 on an oven-dry weight basis.

(xvii). Of the plant samples (all aerial parts) collected in the Lode Area, 34% (25% on an oven-dry weight basis) contained concentrations of lead above the threshold level. The ratio of the mean of the determinations for lead in the samples from this area to the threshold level for plant ash was 4:1, and 1.7:1 for oven-dry material.

(xviii).Ninety seven percent of the determinations for zinc made on plant samples (all aerial parts) from the Lode Area gave results above the threshold level for zinc in plant ash. On an oven-dry weight basis, 96% of the samples from this area contained above-threshold values for zinc. The ratio of the mean zinc content in the ash of samples from the Lode Area to the threshold level was 33:1, while the corresponding ratio on an oven-dry weight basis was 24:1.

(xix). The difference between the mean copper:zinc ratios in plant samples (all aerial parts) from the Lode Area and the mean background value was highly significant in a statistical sense. Likewise, the difference between the mean ratio in the samples from the Turkey Creek copper occurrence and the mean background value was also highly significant. Examination of the results indicate that a mean copper:zinc ratio below 0.1 for plants was probably indicative of zinc mineralisation in the underlying rocks, and a mean value above 1.0 indicative of copper mineralisati

(xx). In view of the high percentage of samples from the vicinity of both copper and zinc mineralisation which contained anomalous concentrations of ore-metal, it would appear that little advantage is to be gained, in biogeochemical prospecting, by using the copper:zinc ratio in plant samples rather than the absolute values for these metals alone. It is possible, however, that further research in areas where the known ore-deposits were covered by a greater depth of overburden than in the Dugald River Area might indicate that the copper:zinc ratios were more useful in locating copper and zinc mineralisation than the absolute values for these metals in plants alone.

(xxi). The low percentage of samples from the Lode Area containing anomalous concentrations of lead, and the low ratio between the mean of the determinations from this area to the threshold level, suggests that the detection of lead mineralisation by biogeochemical methods in this area might be more difficult than detection of copper or zinc deposits.

(xxii). Widespread variations in metal content occurred among the different aerial parts of the plants sampled, both as regards the species and the metal in question. In sampling for biogeochemical prospecting, therefore, preliminary tests should be carried out and sampling should, where possible, be confined to one part of one species.

(xxiii). Since different plants from one area varied in their uptake of copper, lead and zinc, sampling in biogeochemistry should preferably be restricted to one species. In view of its abundance and wide distribution, Triodia pungens would appear to be the most suitable sampling medium of the herbaceous and shrub species in this region. Though the majority of the species associated with mineralisation showed a more decided enrichment in copper, lead and zinc than samples of T. pungens from the same area, the former have a more restricted distribution and hence are of less value in biogeochemical prospecting. As previously mentioned, however, their occurrence in regions not known to be mineralised may indicate minor zones of copper and zinc enrichment in the underlying soils.

If T. pungens is replaced by other species over part of the area under investigation, then sufficient samples of these species and T. pungens should be collected from localities where they grow together to provide information for the establishment of suitable correlation factors.

SECTION E: SUMMARY OF CONCLUSIONS REGARDING VEGETATION DISTRIBUTION IN THE DUGALD RIVER AREA

(1). Summary of conclusions on the distribution of the major vegetation units

(i). The Low Tree and Shrub Savanna sub-formation occupies the major part of the Dugald River Area. It occurs over a relatively wide variety of habitats, ranging from shallow acid soils on upland regions to deep alluvial soils on the plains. The unit comprises a fairly open cover of low trees, principally Eucalyptus spp., and a sparse to mid-dense shrub layer dominated by Acacia chisholmi and Carissa lanceolata. The coarse xeromorphic grass, Triodia pungens, is the most widespread member of the herbaceous stratum, though the tall herb, Cleome viscosa, and the annual grass, Sporobolus australasicus, are also important. Thickets of Acacia cambagei are found on scattered remnants of lateritic soils, while a Savanna Grassland of Astrebla pectinata and Iseilema macrathera occurs on heavy clay soils near one of the major rivers. The latter are lined by a fringing stand of tall trees.

(ii). The various sub-formations differ not only structurally, but also floristically. In general, little species carry-over takes place between the three major units, whereas within the Low Tree and Shrub Savanna, which comprises five associations, many species carry over from one association to the next. This may be related to the fact that the Thicket and Savanna Grassland sub-formations are found on soils differing markedly from those occupied by the Low Tree and Shrub Savanna. As stated above, the Thicket sub-formation occurs on relicts of lateritic soils which are very high in iron but low in phosphorus. The Savanna Grassland is developed on heavy clay soils, which, by virtue of their low elevation and fine texture, are water-logged during the wet season.

(iii). Although the various factors of geology, geomorphology, relief, soils and drainage are all interrelated and in part interdependent, it would appear that these factors which influence the availability of water to the plants play a dominant role in the distribution of the vegetation units. The nature of the soil is of particular importance. The texture and depth largely determine the drainage status, while variations in the soil reaction seem~~s~~ to influence the distribution of several of the associations within the Low Tree and Shrub Savanna.

(iv). The major and trace element content of the soils varies both between and within the various soil types, and within areas occupied by individual vegetation associations. The generally low level of correlation between the major and trace element status of the soil and the extent of the vegetation units, suggest that the factors described under (iii) above have a greater affect on their distribution.

(2). <u>Summary of conclusions on the distribution of plant species associated with mineralisation</u>

(i). The normal Low Tree and Shrub Savanna, characteristic of skeletal soils in the Dugald River Area, is absent over outcropping or sub-outcropping lead-zinc mineralisation, and over copper mineralisation when set in siliceous or argillaceous host rocks. The more widespread species are here replaced by an assemblage of *Tephrosia* sp. nov., (Dugald R. MMC/DMJP No. 5), *Polycarpaea glabra*, *Eriachne mucronata*, *Bulbostylis barbata* and *Fimbristylis* sp., (Dugald R. MMC/DMJP No. 279). The last-named species is largely confined to zones of copper mineralisation in the hangingwall of the Dugald River Lode. With this exception, the assemblage species are equally abundant on lead-zinc as on copper mineralisation.

(ii). Although most abundant in the vicinity of the ore-deposits, the assemblage species also have a scattered distribution in regions where mineralisation is unknown. In these localities, however, they have not been observed growing together in distinct assemblages as over the mineralised zones.

(iii). Within the mineralised areas, *P. glabra*, *E. mucronata* and *B. barbata* are generally restricted to those regions where the tenor of the ore-metals in the soil is extremely high. On the other hand, *Tephrosia* sp. nov., which tends to avoid these zones, is found on soils having a wider range of ore-metal content than the former species. *Fimbristylis* sp. occupies a rather intermediate position in this respect.

(iv). Factors of relief, drainage, soil texture and depth and the major element content of the soils seem to have little effect on the extent of the assemblages developed over the ore-deposits. High phosphorus contents in the soils of these areas may have an influence on the distribution of the assemblage species, but it appears that the dominant factor is the large quantities of ore-metal in the rooting medium. No single metal has emerged as having a more decisive influence on plant distribution than any other, though it is possible that copper, lead and silver, (which is present in minor amounts in the lead-zinc deposit), are more important than zinc, (see viii).

(v). The herbaceous and shrub vegetation growing over the mineralised zones shows considerable enrichment in the corresponding ore-metals. The general level in the plant, and rate of increase in the plant compared with the concentration in the underlying soil, decreases in the order zinc, copper, lead. Samples of *Triodia pungens*, which was selected as representative of the more widespread plants, showed a lesser degree of metal enrichment in these areas than samples of the assemblage species from the same locality.

(vi). From their areal distribution, it is apparent that the species associated with mineralisation are well-adapted to survival on the metal-rich soils of the mineralised zones. The higher metal enrichment shown by these species compared with T. pungens (v), suggests that this adaptation lies in a better ability to absorb large amounts of the ore-metals than the more widespread plants.

(vii). Marked variations occurred in the rate of increase of the plant lead content in Tephrosia sp. nov., E. mucronata and T. pungens compared with the rate of increase in the lead content in the soils underlying the sampled plants. Similar variations occurred in the case of copper in the first two species. These variations may be related to intraspecific variation within the plants. It is suggested that the species normally associated with mineralisation have evolved separate ecotypes, better-adapted to survival on the ore-deposits, (by ability to withstand high concentrations in their tissues), than the strains occurring in apparently un-mineralised areas. The variation in the rate of increase in the plant lead content in T. pungens may indicate that this species has also evolved a separate strain which is tolerant of the lead-rich soils associated with the lead-zinc mineralisation. It is emphasized, however, that growth experiments are required to confirm these suggestions.

(viii). In contrast to lead and copper, the concentration of zinc in the aerial parts of _Tephrosia_ sp. nov., _E. mucronata_ and _T. pungens_ shows a roughly linear increase with rising concentrations of this metal in the underlying soils. This suggests that zinc is less toxic towards vegetation than the other ore-metals. This is in part borne out by the fact that the more widespread species can apparently withstand higher concentrations of zinc in the substrate than copper or lead. Moreover, the rate of increase in plant material, and the degree of enrichment in the plants, are higher for zinc than in the case of the other ore-metals.

(ix). Separate occurrences of _Tephrosia_ sp. nov. and _E. mucronata_ in regions which are apparently barren of mineralisation may mark the sites of minor copper and/or zinc enrichment in the underlying soils. In some cases the plants from these areas contain slightly anomalous concentrations of copper and zinc. This enrichment in both plants and soils may be related to the presence of mineralisation at depth, but at present this has not been proved. _P. glabra_, _B. barbata_ and _Fimbristylis_ sp. are comparatively rare outwith the mineralised areas, and in barren regions show no distinct association with zones of metal enrichment in the underlying soils.

(x). The deposits of outcropping and sub-outcropping lead-zinc and copper mineralisation are generally devoid of tree, and, apart from _Tephrosia_ sp. nov., shrub species.

With the possible exception of Eucalyptus terminalis, which appears to be able to withstand higher concentrations of the ore-metals in the rooting medium than other trees, none show a direct affinity with mineralisation.

(3). Summary of conclusions regarding the plant prospecting methods

(a). Indicator plant prospecting

(i). From a rapid survey of several copper deposits in the Mt. Isa-Cloncurry mineral field, it appears that the species associated with mineralisation in the Dugald River Area retain their characteristic link with ore-deposits throughout the region. By virtue of their distinctive appearance, which render them visible from a distance of several hundred feet, the species Tephrosia sp. nov., Polycarpaea glabra and Eriachne mucronata would seem to be the most valuable as indicators of mineralisation.

(ii). Tephrosia sp. nov. is a leguminous shrub, growing to a height of 2 m., with bright green foliage, small coral inflorescences and a light brown bark. In the Dugald River Area it generally occurs over a wider area in the vicinity of mineralisation than the other indicator plants, and hence would seem to be the most useful in reconnaissance prospecting. The plant is also found in areas not known to be mineralised, but at some of these localities the shrub marks the site of minor copper and zinc anomalies in the underlying soil. These may be related to mineralisation at depth, but this point requires further investigation.

(iii). The perennial herb, P. glabra, occurs less frequently in regions apparently devoid of mineralisation than Tephrosia sp. nov. The plant is most abundant directly over the zones of outcropping lead-zinc and copper mineralisation, where it forms small clumps, up to ten inches in height. This species is again easily recognised from a distance by virtue of its pinkish-white flowers.

(iv). Eriachne mucronata lends a very distinctive appearance to the vegetation over the ore-deposits in the Dugald River Area. It grows in small tussocks, with numerous culms up to eight inches in height, sparsely covered by small rigid leaves. During the dry season the grass withers to a light straw colour, forming a marked contrast with the darker green colouration of Triodia pungens which generally dominates the herbaceous vegetation on neighbouring, un-mineralised rocks. E. mucronata also has a sparse distribution as a subdominant member of the "normal" vegetation on acidic soils. Where it forms distinct, monospecific communities in these areas, however, the available evidence suggests that its occurrence is related either to mineralisation or to a zone of metal enrichment in the underlying soil.

(v). It is apparent from the above that separate occurrences of the species associated with mineralisation in the

Dugald River Area are not necessarily related to an ore-deposit at depth. On the other hand, it is important to note that where the species form distinct assemblages, then the present evidence indicates that mineralisation is present in the bedrock below.

(vi). Although the indicator plants would seem to be of most value in reconnaissance prospecting for base metals, their distribution over known ore-deposits may also be useful as a guide to the surface extent of the mineralised zone.

(vii). The distribution of the indicator plants in the Dugald River Area suggests that they have a marked intolerance of basic soils. Hence copper mineralisation when set in calcareous host rocks, as in the limy calc-silicates of the extensive Corella Formation, seems unlikely to be marked by the occurrence of these species.

(b). <u>Biogeochemical prospecting</u>

(i). Samples of herbaceous and shrub vegetation collected over lead-zinc and copper mineralisation in the Dugald River Area show a decided enrichment in the corresponding ore-metals compared with the normal concentrations in herbaceous vegetation from barren areas. Plants collected from areas with minor ore-metal anomalies in the soils, however, were only slightly, if at all, enriched in these metals. Hence, on the present evidence, analysis of herbaceous and shrub plants from regions where mineralisation is unknown will only detect unsuspected ore-deposits where a considerable amount of ore-metal has been released into the overlying soil or alluvium.

(ii). The percentage of samples from regions of lead-zinc mineralisation in the Dugald River Area containing anomalous concentrations of zinc was considerably higher than those with anomalous quantities of lead. The corresponding percentage from an area of copper mineralisation was similar to that for zinc. It appears, therefore, that the presence of unsuspected zinc and copper mineralisation will be more easily detected by the biogeochemical method than deposits of lead ore.

(iii). In view of the high percentage of samples from areas of copper and zinc mineralisation containing anomalous concentrations of the corresponding ore-metals, there would seem to be little advantage in using the copper:zinc ratios in plants as a guide to ore rather than the absolute values of the metals alone.

(iv). Comparison of the concentrations of ore-metal in the flowers, fruits, leaves and stems of the plants analysed indicates that wide variations occur in the distribution of the metals. The distribution varies according to the species and metal in question, and, in some cases, according to the tenor of the metal in the soils. Thus no plant organ has emerged as showing a more consistent relationship to the ore-metal content in the substrate than other aerial parts of the plant. After preliminary tests, therefore, biogeochemical sampling should, where possible, be confined to one part of a single species.

(v). With this in mind, the choice of a suitable medium for biogeochemical sampling largely depends on the abundance and distribution of the plants occurring within the area. The investigation in the Dugald River Area indicates that the leaves of *Triodia pungens* show a significant enrichment in copper, lead and zinc when collected from plants growing over deposits of these metals. Although the majority of the species comprising the assemblage over the ore-deposits show a higher degree of enrichment than *T. pungens*, they have a more restricted distribution and hence are of less value in biogeochemical prospecting. *T. pungens* is widespread, not only in the Dugald River Area, but also throughout the greater part of the Mt. Isa-Cloncurry mineral field. It would therefore appear to be the most suitable member of the herbaceous and shrub vegetation for use as sampling medium in biogeochemical prospecting for base-metals in the region.

PART IV: THE BULMAN AREA

Introduction

The Bulman Area lies in the southern part of the Arnhem Land Aboriginal Reserve in the Northern Territory, (Fig. 40). Outcrops of lead ore in the region had been discovered and worked during the years 1909-1911, while further investigations in the years 1951-1952 had revealed the presence of high-grade oxidised zinc ore, (Sturmfels, 1952).

The vegetation of the region, dominantly Savanna Woodland though Savanna Grassland is also important, differs in structure and specific composition from that in the Dugald River Area. Moreover, the soils, geology, and host rocks of the mineralised zones at Bulman bear little resemblance to those in the former area. These factors afforde suitable contrasting conditions for study of plant distribution in the vicinity of mineralisation.

The geology of the area was fairly well known from work by Company geologists, and one of these, (Sturmfels, ibid), has commented on the close correlation between the distribution of certain plants and the ore-deposits. A preliminary survey by M.M. Cole had also led to the discovery of Polycarpaea spirostylis at certain localities within the region. This species has been reported as occurring in the vicinity of copper deposits in eastern Queensland by Skertchley, (1897).

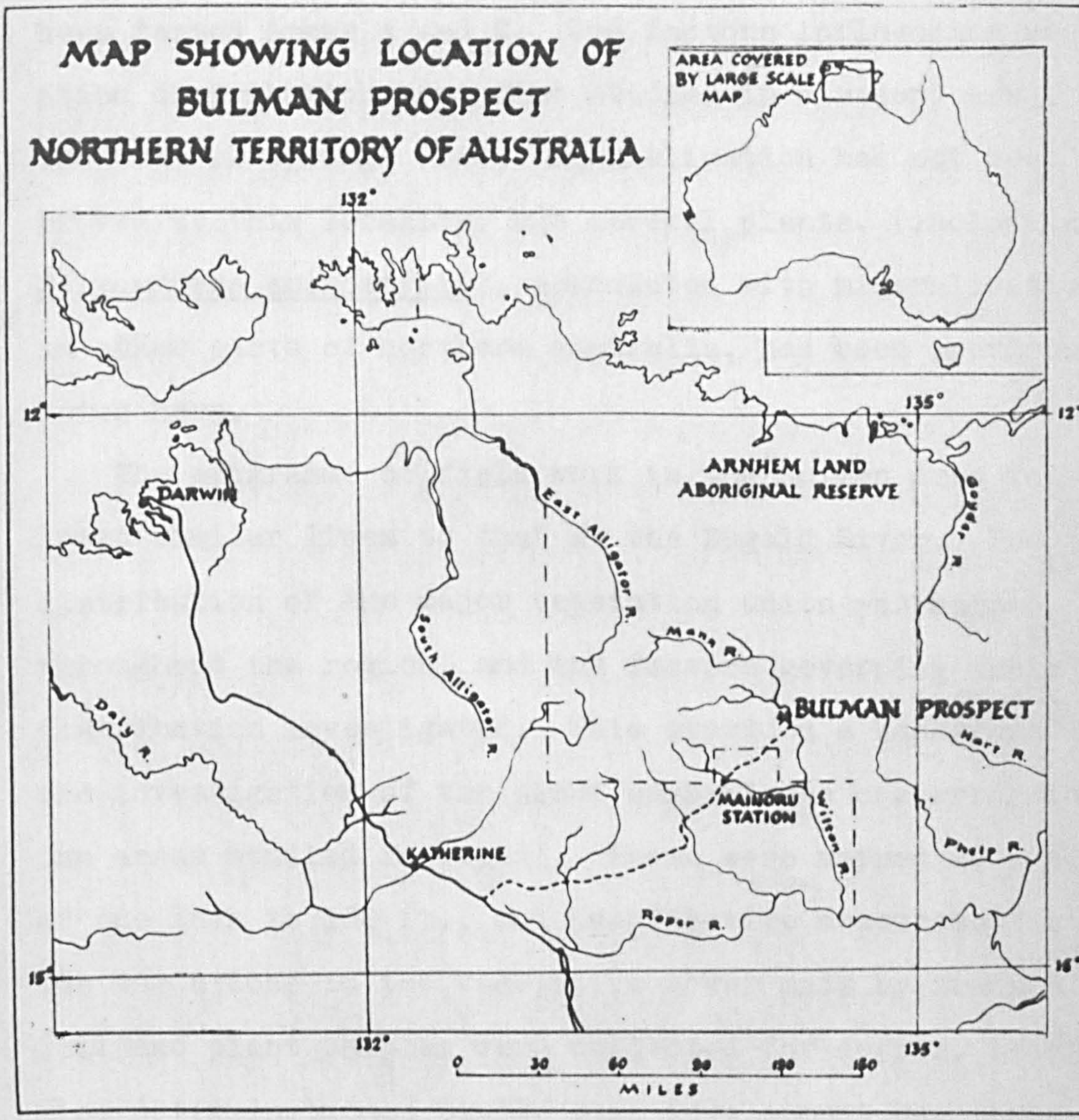

MAP SHOWING LOCATION OF
BULMAN PROSPECT
NORTHERN TERRITORY OF AUSTRALIA
AREA COVERED
BY LARGE SCALE
MAP
132°
12°
135°
12°
DARWIN
ARNHEM LAND
ABORIGINAL RESERVE
East Alligator R.
South Alligator R.
Goyder R.
Daly R.
Mann R.
BULMAN PROSPECT
Hart R.
MAINORU
STATION
Wilton R.
Phelp R.
KATHERINE
Roper R.
15°
15°
132°
135°
0 30 60 90 120 150
MILES

FIG. 40.

The major occurrence of lead-zinc ore in the region lies in dolomite, limestone and chert rocks, which form two low hills rising above an alluvial plain. These have been termed Areas A and B. The factors influencing vegetation distribution were also studied in a second area, the Weimool Springs Grid. Mineralisation has not been proved at this locality, but several plants, (including *Polycarpaea spirostylis*), associated with mineralisation in other parts of northern Australia, had been previously noted here.

The programme of field work in the Bulman Area followed similar lines to that at the Dugald River. The distribution of the major vegetation units was mapped throughout the region, and the factors governing their distribution investigated. This provided a background for the investigation of the plant assemblages occurring in the areas studied in detail. These were mapped at a scale of one inch to 100 ft., and quantitative measurement of the variations in the vegetative cover made by transects. Soil and plant samples were collected for copper, lead and zinc determination. Little soil development has taken place over the upland parts of Areas A and B, but in the Weimool Springs Grid Area greater diversity occurs. Variations in the soil cover at the latter locality have therefore been studied in profile pits.

SECTION F: THE CLIMATE, GEOLOGY, PHYSIOGRAPHY AND SOILS

(1). Climate

The area has no climatic stations, and hence accurate statistics are not available. However, Specht and Mountford, (1958), report that records for Mainoru Homestead, (Fig. 40), show that in the period 1954-1957, the average rainfall was about 27 ins. per annum. This, they consider, is exceptionally low, and from the evidence of the rainfall map, an average of about 35 ins. can be expected.

The climate is tropical, with well-defined wet and dry seasons, the first extending from October to the end of March. During the dry season the dominant winds are from the south-east, but in the summer the wind direction is reversed with the onset of the north-west monsoon. There is then a consequent increase in temperature and humidity. Light showers, mists and morning fogs are quite common in the dry season, while dews occur throughout the year.

Mean monthly rainfall and temperature figures for Darwin and Katherine, (Fig. 40), are shown in Table 27. It is probable that the climate of the Bulman region is closer to that at the latter station.

The climate of the Bulman Area resembles that of the Dugald River in the seasonal distribution of the rainfall and the coincidence of the period of maximum temperatures with that of high rainfall. At Bulman, however, the increased influence of the summer monsoon produces an average

Table 27 : Mean Monthly Rainfall and Temperature Figures for Darwin and Katherine, (after Perry, 1960).

	Jan.	Feb.	Mars	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Oct.- Mars	Apr.- Sept.	Annum
Rainfall															
Darwin, inches	16.18	12.37	11.18	3.08	0.33	0.09	0.01	0.60	0.60	1.93	4.32	8.57	54.55	4.13	58.68
Katherine, inches	9.14	7.07	5.89	0.78	0.27	0.12	0.03	0.01	0.16	1.15	3.02	7.81	34.08	1.37	35.45
Temperature													Mean		
Darwin, Max.	89	88	89	90	89	86	86	88	90	91	91	90	89		
(14 years) Min.	77	76	76	74	71	68	67	69	74	77	77	77	73		
°F. Range	12	12	13	16	18	18	18	19	16	14	14	13	16		
Katherine, Max.	95	94	95	94	91	86	87	90	96	100	100	98	94		
(15 years) Min.	75	74	73	68	62	56	56	59	67	75	76	76	68		
°F. Range	20	20	22	26	29	30	31	31	29	25	24	22	26		

annual rainfall about twice that in the Dugald River Area.

These factors have a marked affect on the vegetation of the region. Many of the trees are dry-season deciduous, thus cutting down transpiration during this critical period. The aerial parts of the perennial grasses die back in the winter, growth being resumed from vegetative buds at the onset of the following rains. The higher rainfall at Bulman leads to more rapid growth in the wet season compared with that in the Dugald River Area. Thus many of the grasses reach a height of six to eight feet in the present area, while at the Dugald River the normal height of the herbaceous vegetation was only one to two feet. The dominant members of the tree storey at Bulman are also considerably taller than those of the latter region.

(2). General geology

Apart from the investigations by Sturmfels, (1952), and Campbell, (1956), little work has been carried out on the geology of this part of the Northern Territory.

The age of the rocks outcropping in the Bulman Area is not definitely known, estimates ranging from Upper Proterozoic to Middle Cambrian. They comprise three formations, (Table 28), the beds of all three being roughly horizontal over most of the region. As evidenced by fragments of the Bulman Formation in the Weir Conglomerate, an unconformity is probably present between the two formations.

Table 28: Stratigraphical Sequence of the Rocks in the Bulman Area

Formation	Max. thickness observed, (ft.)	State of Alteration	Lithology
Weir Conglomerate	70		Quartzites derived from conglomerate sandstones grits and breccias.
	Probable Disconformity.		
Wilton Sandstone	110		Sandstones with dolomite beds, partly silicified.
Bulman Formation		(a) Altered Quartzitic Alteration	Quartzites and silicified rocks derived from limestones and dolomites
		Contact Metamorphic Alteration	Siliceous dolomite rock with chert layers.
	130^+	(b) Unaltered (Bedded calcareous facies	Limestones, dolomite rock and marls wit sandstone layers.
		(Reef facies	Massive dolomite rocks formed of Collenia
	80^+	Sandstone-limestone-shale facies	Upper part interbedded sandstones ar dolomite limestones. Lower part shale

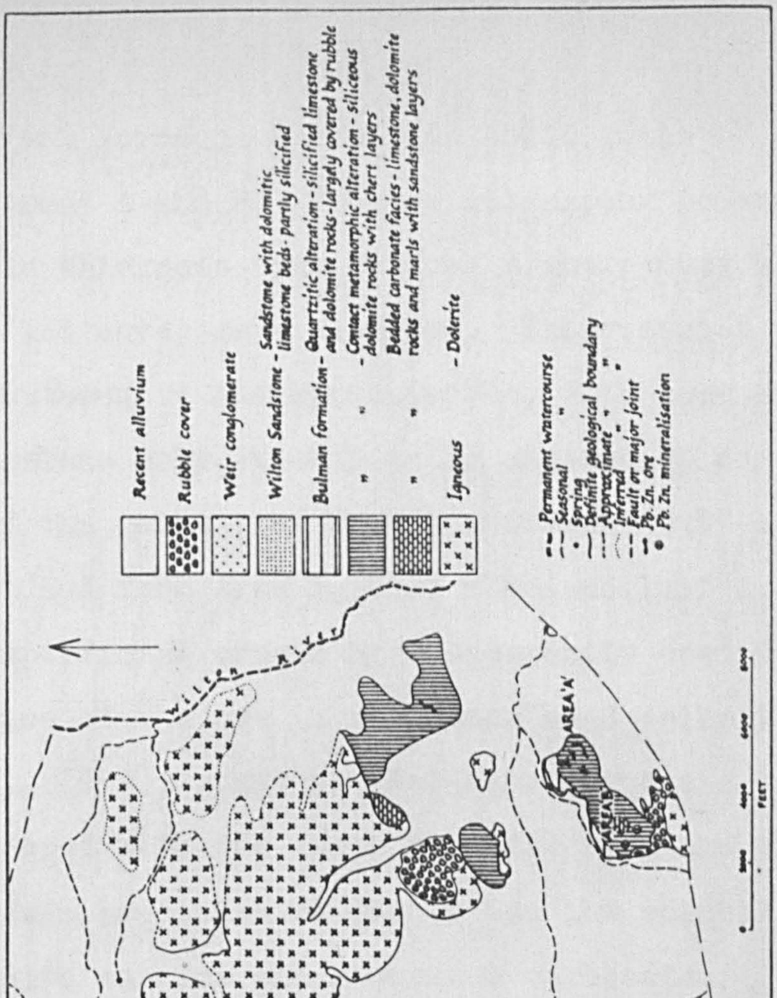


Fig. 41 Geological Map of Bulman,
showing Study-Areas

Surface Crusts

Zinc rich surface crusts with solid lumps of galena occur on Areas A and B. They do not appear to exceed a few feet in thickness even on Area A where they are best developed and cover several acres. They consist essentially of smithsonite and hydrozincite, with some solid lumps of galena only superficially altered to cerussite. Samples of the crust from Area A averaged 29.7% zinc and 1.8% lead, and from Area B, 7.1% zinc and 1.1% lead.

The superficial crusts have apparently been derived by oxidation of the ore in the decomposed dolomite rocks. Sturmfels, (1952), suggests that zinc carbonate bearing waters reacted with the fresh dolomite rock and the zinc carbonate was precipitated due to its low solubility as compared with calcium and magnesium carbonate.

Unoxidised Ore

The occurrence of unoxidised lead ore, and to a minor degree also of zinc ore as found at Bulman, in an area of low relief and tropical climate with a yearly rainfall of about 35 ins. is most unusual. The following explanations have been offered, (Sturmfels, ibid).

A. A more or less impervious cover of sediments of considerable thickness, which was removed only recently, prevented the access of oxidising agencies. It is possible that the Prospect formed until Recent times part of the tableland still existing to the south west and south;

the surface would have been about 300 ft. higher than it is today. If this was so, it must be assumed that the area was uplifted and exposed to fast erosion in Recent times.

B. Reducing conditions as they are found below a zone of lateritisation prevailed until Recent times. The laterite was removed by a young erosion. Recent uplift and erosion would be required, though to a lesser extent than in the above theory.

C. The carbonate rocks surrounding the lead-zinc occurrences were more soluble than the ore itself. Acid solutions attacked preferentially the carbonate rocks. Their leached and oxidised residues, (decomposed dolomite rocks), covered the ore completely. Oxidation of the ore was thus prevented, particularly the oxidation of the galena, but for a thin skin of cerussite. In this case, it is not necessary to assume Recent uplift and erosion.

Sturmfels remarks that, "it is realised that none of the above theories offer a completely satisfactory explanation". In the view of the present writer, explanation B, or possibly a combination of A and B, is the most likely, since it agrees with the geomorphological evidence to be presented later.

(4). Physiography

The region lies on a gently undulating plateau, probably between 300-500 ft. above sea level, though the exact altitude is unknown. Above this general level rise the steep-sided conical hills of Mt. Weir and Mt. Marumba. The former, lying $1\frac{1}{2}$ miles south-west of the Bulman Prospect, rises to a height of approximately 350 ft. above the plateau, while Mt. Marumba, about $4\frac{1}{2}$ miles to the east, is approximately 320 ft. above the general level.

Each of the major rock types occurring in the area give rise to distinctive upland topography. To the north, much of the area is occupied by low rounded hills of chert, which masks the underlying bedrock. Dolerite outcrops as extensive areas of rocky country raised above the enclosing alluvial-filled vallies, (Plate 22). The limestones, dolomites and cherts of the Bulman Formation form fairly steep-sided hills, frequently with the development of Karst topography in the softer beds, (Plate 30).

The area is drained by the Wilton River, which forms the eastern margin of the region mapped and flows south and east into the Gulf of Carpentaria. Permanent water is confined to waterholes on the Wilton and to several limestone springs, the largest being Weimool Springs about $3\frac{1}{2}$ miles north-west of the Prospect. The springs give rise to intermittent ramifying streams, which flow eastwards across alluvial plains to join the Wilton River.

(5). Evolution of the landscape

Within the Bulman region, three possible erosion surfaces have been recognised. From oldest to youngest these have been named Surface A, Surface B and Surface C. The geomorphology of the area bears many similarities to that of the Daly River Basin, lying some 200 miles to the west, (Fig. 40), and described by Wright, (1963). This author also recognises three erosion surfaces, which he terms, from oldest to youngest, the Bradshaw, Maranboy and Tipperaray Surfaces.

Surface A

In the immediate Bulman Area this surface is represented only on the summits of Mt. Weir and Mt. Marumba. A further remnant, Mt. Jean, lies several miles north of the Prospect, but the main development occurs to the south, where the surface is represented on the summits of extensive sandstone and dolerite hills.

The oldest erosion surface in the Daly River Basin, Wright's, Bradshaw Surface, is associated with laterite development. In this region, intact lateritic profiles, i.e. ferruginous, mottled and pallid zones, occur on plateaux and ranges. No intact profiles were found in the Bulman Area, but a thin veneer of laterite gravel, which probably represents ferruginous zone material, was noted on the summit of Mt. Weir. This overlies about 70 ft. of silicified sandstones and conglomerates, presumably silicified during the period of laterite formation. No mottled zone material was observed, but as this is generally made up of softer material it is possible that it has been eroded off the summit of Mt. Weir, leaving a few remnants of the overlying, more resistant, ferruginous zone.

At Bulman, therefore, erosion of the oldest surface has apparently reached a more advanced stage than in the Daly River Basin. Whether the two surfaces are of the same age, however, would require extensive mapping in the region separating the two areas.

Surface B

This erosion surface is one of considerable extent. To the north of the Bulman Prospect it occurs on the hill summits in an extensive area of undulating country underlain by chert. The chert is light-grey in colour with laminations of darker material, and generally has a fresh, unaltered appearance. In the Weimool Springs Grid area, (Fig. 41), much of the chert is masked by 2 to 3 ft. of laterite nodules and chert inclusions in a grey or reddish sandy matrix. This material is interpreted as a detrital laterite formed from the ferruginous zone of a stripped lateritic profile, while the underlying chert represents the pallid zone. The gradational, mottled, zone is represented by traces of red and yellow mottling near the base of the laterite gravel horizon.

In the Daly River Basin, the second oldest erosion surface, the Maranboy Surface, was developed by re-weathering of the Bradshaw pallid zone. In most areas it was produced by stripping of the upper, less-silicified part of the Bradshaw profile, (Wright, ibid). The Maranboy Surface is also associated with a lateritic weathering profile, less deep, however, than that underlying the Bradshaw Surface. In the type area it comprises lateritic grey and red earths underlain by about 6 ft. of ironstone in a sandy matrix. The ironstone is partly detrital and contains fragments of re-cemented ironstone and inclusions of pallid zone rock. This horizon overlies about 60 ft. of pallid zone rock, which is commonly powdery in argillaceous rocks, crumbly and honey-combed in coarser rocks. Secondary iron enrichment has occurred along joint and bedding planes in the upper parts. This material is thought to have been formed by desilicification of Bradshaw pallid zone rock during re-weathering associated with the Maranboy Surface.

There is a general similarity between the Maranboy weathering profile described by Wright, (ibid), and that associated with Surface B as exposed in the Weimool Springs Grid. However, they differ in the absence of the lateritic grey and red earths. Another, more important difference, is that the Surface B profile at Bulman shows little indication of desilicification or secondary iron enrichment.

Wright states that, "although the pallid zone underlying the Maranboy ferruginous zone has been identified with the Bradshaw pallid zone, the powdery and honey-combed texture are in strong contrast with the resistant Bradshaw silicified rock which typically occurs beneath it".

As previously mentioned, however, the pallid zone material underlying Surface B in the Weimool Springs Grid is strongly silicified, and in this respect it resembles the presumed pallid zone rock underlying Surface A as exposed on the summit of Mt. Weir. It is therefore possible that the two profiles are of the same age, the difference in elevation, (100 to 200 ft.), being due to variations in the original relief of Surface A.

If this be the case, then only one period of lateritisation has occurred in the Bulman Region, i.e. that associated with Surface A. This agrees with the findings of Stewart, (1956), for the Katherine-Darwin area, who reports only one period of laterite formation, probably in the Tertiary. From his description, the laterite profiles exposed in the Bulman Region would appear to have been formed during the same period.

Around the Bulman Prospect itself, much of Surface B has been destroyed by subsequent erosion, but it is still preserved on the summits of the limestone, dolomite and dolerite hills in this area, and as rock-cut terraces on the lower slopes of Mt. Weir. These show a rough summit accordance with the chert hills to the north.

Surface C

This is the youngest erosion surface occurring in the Bulman Region. It forms broad plains covered by Recent alluvium, (Fig. 41), cut below the level of Surface B and separated from it by low, discontinuous escarpments. The surface has apparently advanced by erosion of the bedrock, as around the Bulman Prospect, and by removal of the ferruginous and pallid zone material associated with Surface A.

At the present day the plains are masked by a variety of alluvial deposits, including heavy black clays, fine grey calcareous material, and stretches of fine white material, the "Bull Dust", apparently derived by erosion of pallid or mottled zone material.

Stewart, (1956), has postulated a rise in sea level of some 200 ft. in the Pleistocene for the Katherine-Darwin area. Extensive estuarine alluvium has been formed, while the more mature streams of the hinterland have deposited wide flood plain deposits.

In view of the proximity of the two areas, (Fig. 40), it is probable that the Bulman Region was also affected by this submergence. The consequent rise in base level lessened the erosional powers of the rivers, and allowed the deposition of the extensive alluvial deposits.

Surface C bears many similarities to the Tipperary Surface of Wright, (ibid), in the Daly River Basin. In the lower parts of this unit, however, even younger erosion surfaces are developing at the present day.

The geomorphological history of the Bulman region may be therefore summarised as follows:

(i). The formation of Surface A, probably in the mid-Tertiary; on this surface deep lateritic profiles were developed.

(ii). Uplift and erosion, leading to the destruction of Surface A, apart from isolated remnants such as Mt. Weir. Surface B was developed by re-weathering of the lateritic profile associated with Surface A.

(iii). A final period of uplift, with erosion of the earlier surfaces and the initiation of Surface C.

(iv). A rise in sea level in the Pleistocene, with consequent rise in the base level of the rivers and the accumulation of erosional products on Surface C.

(6). Soils

The soils being formed in the Bulman Region at the present day are relatively immature. Basically they comprise skeletal soils and soils developed on alluvium. In addition, a large part of the area north of the Bulman Prospect is occupied by soils derived from the ferruginous and pallid zones of a lateritic weathering profile, thought to have been formed during the Tertiary, (see previous section). Weathering of the ferruginous zone has given rise to relatively shallow, fine-textured, soils with abundant laterite nodules and inclusions of pallid zone rock. Where the ferruginous zone has been removed by erosion, weathering of the underlying pallid zone rock has produced a variable depth of reddish clay with abundant inclusions of pallid zone material. These soils are more fully discussed in the description of the Weimool Springs Grid, (Section I).

(a). Skeletal Soils

Skeletal soils occur on the upland areas surrounding, and including, Areas A and B, (Fig. 41). The soils are shallow and gravelly and lack profile development. Over the limestone and dolomite hills the gravel fraction is dominated by fragments of the chert rock with which the carbonate rocks are interbedded. Presumably the weathering products of the less resistant limestone and dolomite have been largely removed in solution in rain water. On the dolerite hills, pockets of coarse, granular rotted dolerite occur between rounded boulders and outcrops of the underlying bedrock, (Plate 23).

The upland areas are surrounded by a bordering zone of finer-textured soils, in part skeletal and in part developed from material washed down from the neighbouring high ground. At the base of the limestone, dolomite and chert hills the soils generally consist of a dark brown to grey sandy clay or clay with rock fragments. At the foot of the dolerite hills, the soils are of coarser texture, consisting essentially of dolerite in all stages of decomposition.

(b). Alluvial Soils

Regions of lower elevation in the Bulman Area are largely occupied by Recent alluvium, (Fig. 41). By far the most abundant type is a dark grey or black clay soil which gives rise to the "Black Soil Plains". The plains are seasonally flooded and, as the soil dries out, deep vertical cracks are developed. The soils are basic on the surface, (pH 7-8).

South and east of Weimool Springs permanent swamp conditions exist along the small streams draining the Springs. In this area, extensive stretches of fine-textured calcareous soils were encountered, markedly different from the surrounding dark grey clay soils. In one locality, large masses of nodular calcrete, surrounded and enclosed by the fine-textured calcareous material, were found on the surface, (Plate 29). The surface exhibited gilgai development, i.e. mounds and depressions, presumably caused by swelling and shrinking within the soil profile due to the alternate waterlogging and dessication. The calcrete has probably been formed by solution and re-deposition of lime within the calcareous material. As regards the lime itself, this has apparently been deposited from the water issuing from the Weimool Springs. Since much of the region is underlain by limestone, the ground water is likely to be exceedingly rich in dissolved salts. During the wet season, the volume of water issuing from the Springs will show a large increase and the surrounding area will be flooded. As the dry season advances, the alluvium will dry out and the dissolved salts will be deposited as lime.

(c). Discussion

The distribution and characteristics of the soils occurring in the Bulman Region have been influenced by a number of factors, of which the geology and past and present geomorphological processes are probably the most important.

Climatic processes have also had a marked influence on the soils, however. Thus the laterites were formed, probably in the Tertiary, (Stewart, 1956), under more pluvial conditions than obtain in the region at the present day. The strongly seasonal nature of the rainfall at present has had an influence on the soils developed on the upland regions where bedrock is exposed. These are shallow and gravelly, but if the climate had allowed the growth of a more luxuriant vegetation throughout the year, then possibly the soil would have been stabilised by the binding action of the plant roots and a greater depth would have accumulated. Moreover, during the wet season the rainfall is likely to be intense, causing rapid erosion of the weathering products formed on the upland regions.

The geology is obviously the most important single factor determining the distribution and nature of the skeletal soils developed on the hills surrounding the Bulman Prospect.

After the period of laterite formation, the Bulman

Region was uplifted and the subsequent erosion has removed the lateritic weathering profile over a large part of the area. Skeletal soils have been developed on the exposed bedrock. In places, however, the stripped lateritic profiles remains, though younger soils have been developed on the exposed ferruginous and pallid zones, as in the Weimool Springs Grid Area.

The Pleistocene submergence postulated by Stewart, (ibid), has allowed the accumulation of the extensive alluvial deposits on the lower terrain. These are now represented by the heavy dark grey or black clay soils and the fine-textured grey calcareous soils.

SECTION G: THE MAJOR VEGETATION UNITS OF THE BULMAN AREA

(1). Introduction

The following description of the vegetation of the Bulman Area is based on reconnaissance mapping over an area measuring approximately 5 miles wide and 3 miles long, (Fig, 42). The dominant species of each stratum were plotted on aerial photograph enlargements in the field. Where possible, the boundaries between the various associations and communities were also plotted directly, but in some of the more inaccessible regions these had to be inferred from the aerial photographs.

Previous investigations into the vegetation of the northern part of the Northern Territory have been reviewed in the Introduction to this thesis. As far as is known, the vegetation of the Bulman Area has been the subject of only one report, that by Bateman and Specht, (in Specht and Mountford, 1958). However, these authors apparently visited only that part of the region east of the Wilton River. Few of the species they list were found by the present writer and their description of the vegetation bears little similarity to the present one.

The units used in the classification of the vegetation of the Bulman Area are indicated in Table 29., together with their deduced equivalents in other investigations. The more widespread vegetation types have been classed as associations while those which occur on more restricted

Table 29: Comparison of the Vegetation Units in the Bulman Area with those of other Investigations.

Sub, Formation (Cole, 1963)	Sub-form (Williams, 1955)	Katherine-Darwin Area (Christian & Stewart, 1953)	Arnhem Land (Specht & Mountford, 1955)	Bulman Area Present study
Savanna Woodland	Tropical Layered Woodland	Mixed Open Forest	Tall Open Forest	Erythrophleum chlorostachys, Eucalyptus spp., Gardenia megasperma, Chrysopogon pallidus, Andropogoneae indet. association
	Tropical Deciduous Woodland	Deciduous Open Forest		Cochlospermum fraseri, Acacia pallida, Vetiveria elongata, Heteropogon contortus community
		Orchard Community		Gardenia megasperma, Erythrophleum chlorostachys, Vetiveria elongata, Chrysopogon pallidus community.
Savanna Parkland/ Grassland		Parkland	Savanna Woodland	Eucalyptus tectifica, E. confertiflora, Hakea arborescens, Heteropogon contortus, Andropogoneae indet., Iseilema vaginiflorum association
Savanna Grassland	Tropical Tussock Grassland	Grassland		Sorghum sp., Chionachne cyathopoda, Iseilema vaginiflorum, with Terminalia platyphylla & Tristania grandiflora - association
		Palm Scrub	Pandanus spiralis association, (in part)	Pandanus sp., Timonius timon, Heteropogon contortus, Flaveria australasica community
Savanna Grassland		Swampy Grassland	Savanna Formation	Imperata cylindrica var. major, Flaveria australasica community
Thicket				Pipturus argenteus, Melaleuca viridiflora community.

habitats have been classed as communities. On this basis, three associations and five communities have been recognised.

Presumably by virtue of the more humid climate and higher temperatures, the region is occupied by a more luxuriant and taller vegetation than the Dugald River Area. It will be recalled that the most widespread sub-formation in the latter area was Low Tree and Shrub Savanna, while at Bulman a tall Savanna Woodland covers the largest area. The height of the dominants of the herbaceous layer also differs. In the Dugald River Area, the most widespread grass, Triodia pungens rarely exceeds a height of 2 ft., while at Bulman many of the perennial species in the Savanna Grasslands reach 8 or 9 ft. in height during the wet season. Moreover, the herbs and grasses in the Bulman region generally form a fairly dense cover throughout the year. At the Dugald River, however, much of the ground is bare during the dry season.

In the following description, the associations and communities occurring on the well-drained upland regions with acid to neutral soils are discussed first, followed by those found at progressively lower elevations where the soils are generally poorly-drained and increasingly calcareous.

A comparative list of the plant species found in the Bulman Area is given in Table 36. This has been prepared

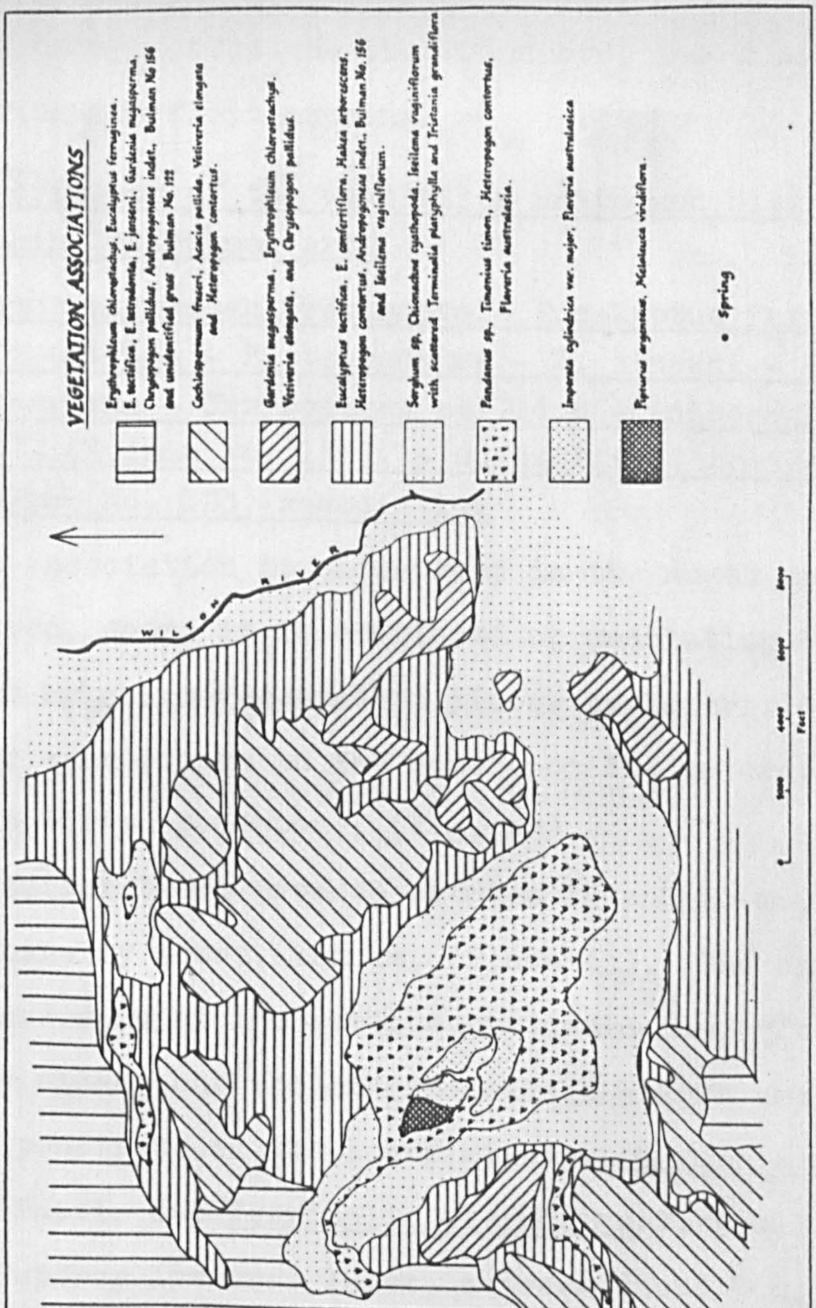


Fig. 42 Vegetation Map of the Bulman Area

from the data recorded on the transects, and from notes made during the field mapping.

(2). Description of the vegetation units and distribution within the Bulman Area

(a). Erythrophleum chlorostachys - Eucalyptus ferruginea - E. tectifica - E. tetrodonta - E. jenseni - Gardenia megasperma - Chrysopogon pallidus - Andropogoneae indet. (Bulman No. 156), - unidentified grasses, (Bulman No. 123) association

This association is widespread in the north and west of the area, where it is developed on undulating country underlain by chert veneered in places by lateritic gravel. A smaller area occurs in the south, on the outcrop of the siliceous Wilton Sandstone, (Fig. 42).

The taller trees grow to between 15 and 20 m., with thin, generally erect, trunks, (Plate 41). The crowns are sparse, and many of the species are deciduous. The spacing is fairly close, but the sparse foliage allows ample sunlight to penetrate to the lower strata. Gardenia megasperma F. Muell. and Terminalia pterocarya F. Muell. form a fairly sparse low tree layer, between 5 and 7 m. in height.

The composition of the tree stratum alters where the underlying chert comes to the surface, or where drainage lines traverse the area. In these environments, most of the other tree species go out, and a woodland of Erythrophleum chlorostachys Baill. and Eucalyptus tectifica

F. Muell. is developed.

The shrub layer is sparse, the low (2 ft.), Petalostigma quadriloculare F. Muell.,being virtually the sole member. There is a fairly dense ground storey of tall grasses, including Chrysopogon pallidus Domin., Andropogoneae indet, (Bulman Nos. 135 and 156), Heteropogon contortus (along drainage lines), and an unidentified grass, Bulman No. 123. The lateritic gravel is occupied by a characteristic assemblage, but this, and other variations in the vegetation, will be more fully discussed in the description of the Weimool Springs Grid, (Section I).

(b). Cochlospermum fraseri - Acacia pallida - Vetiveria elongata - Heteropogon contortus community

Areas of outcropping dolerite carry this community, which consists of a fairly dense growth of tall grasses with scattered low trees, (Plate 22). The kapok bush, Cochlospermum fraseri Planch, has a thin erect trunk, with a few branches bearing yellow flowers and large green oval fruit. In common with most of the trees found in this community, it is virtually leafless during the dry season. Acacia pallida F. Muell. grows to a height of 5 m., with a thin trunk covered by light grey corky bark. Other tree species include Brachychiton gregorii F. Muell., Grevillea dimidiata F. Muell., Gardenia megasperma, Eucalyptus patellaris F. Muell. and Erythrophleum chlorostachys.

A shrub stratum is absent, but the ground storey is

Plate 22 Cochlospermum fraseria, Acacia pallida Vetiveria elongata on outcropping dolerite in the Bulman Area

Plate 23 Residual Soil on dolerite

Plate 22 Cochlospermum fraseria, Acacia pallida Vetiveria elongata on outcropping dolerite in the Bulman Area

Plate 23 Residual Soil on dolerite

fairly dense, dominated by the tall grasses Vetiveria elongata (R.Br.) Stapf. ex C.F. Hubbard, and Heteropogon contortus. The intervening spaces carry a sparse cover of annual herbs and grasses, including the following; Cleome viscosa, Boerhavia diffusa, Polycarpaea corymbosa, Ptilotus fusiformis Poir., Pterocaulon verbascifolium, Indigofera linifolia Retz. and Eriachne obtusa R.Br.

The community is quite widespread within the area, though restricted to the dolerite outcrops. The surface here is formed of rounded boulders and masses of the parent rock, with the intervening areas occupied by a thin cover of fairly coarse grained degradation products, (Plate 23). The majority of the species occurring in this environment are also found in the following community: with the exception of Vetiveria elongata, however, they here occupy a sub-dominant position.

(c). Gardenia megasperma - Erythrophleum chlorostachys - Vetiveria elongata - Chrysopogon pallidus community

Like the last, this community ~~unit~~ comprises a generally sparse cover of low trees, a poorly developed shrub stratum, but a dense ground storey of tall grasses and smaller herbs, (Plate 32).

This community covers the greater part of Areas A and B, and a full description will be given in the discussion of the vegetation of these areas, (Section H). It is normally restricted to the low hills of the carbonate rocks of the Bulman Formation, though a small area is also developed on chert gravel south of Weimool Springs, (Figs. 41, 42).

(d). Eucalyptus tectifica - E. confertiflora - Hakea arborescens - Heteropogon contortus - Andropogoneae indet. (Bulman No. 156) - Iseilema vaginiflorum association

This rather ill-defined association occupies an intermediate zone between those associations and communities described above, which are generally confined to regions of upland topography, and those discussed below which occur on lower terrain.

Eucalyptus tectifica and E. confertiflora F. Muell. are tall (16 to 20 m.) erect trees, (Plate 24), the former with a covering of light grey fibrous bark and the latter with a smooth white bark. Other tall trees include Terminalia platyphylla F. Muell., Eucalyptus patellaris F. Muell., E. bigalerita F. Muell. and Bauhinia cunninghamii.

An open cover of low trees may be present in some areas Of these, Gardenia megasperma is the most common, while Hakea arborescens R.Br. is also frequent. Acacia pallida may also be important in places. In some of the wetter areas, Melaleuca viridiflora Gaertn. forms separate stands of small, erect, closely spaced trees.

The herbaceous vegetation is variable in character, and in areas frequented by buffalo and cattle much of the groun

Plate 24 *Eucalyptus confertiflora* and *Terminalia platyphylla* on alluvium

Plate 25 *Tristania grandiflora* and *Sorghum* sp. (Bulman No. 184) on the Black Soil Plains

Plate 24 Eucalyptus confertiflora and Terminalia platyphylla on alluvium

Plate 25 Tristania grandiflora and Sorghum sp. (Bulman No. 184) on the Black Soil Plains

is bare. However, Andropogoneae indet., (No. 156), Heteropogon contortus and Iseilema vaginiflorum Domin. are generally present, and may form a dense grassland in places. Eragrostis japonica Trin., Fimbristylis phaeoleuca S.T. Blake and Elytrophorus spicatus A. Camus, occur in clayey depressions in some of the wetter areas.

The soils are mainly residual or colluvial in origin, consisting generally of a variable depth of dark brown or grey sandy clay to clay with scattered gravel-size fragments derived from the neighbouring hills.

(e). Sorghum sp. (Bulman No. 184) - Chionachne cyathopoda - Iseilema vaginiflorum - Terminalia platyphylla - Tristania grandiflora · association

Where the shallow soils described above give way to deeper clay soils, the vegetation alters to tall savanna grassland with scattered tall trees. Sorghum sp. (Bulman No. 184) grows to over 8 ft. and Chionachne cyathopoda F. Muell. to 6 ft., while Iseilema vaginiflorum is generally less than 2 ft. These species, with, in places, Heteropogon contortus, Andropogoneae indet. (Bulman No. 156), and the tall (8 ft.) herb, Sesbania aculeata Poir. form a very dense growth over most of the area.

The trees Tristania grandiflora and Terminalia platyphylla F. Muell. are characteristic of the environment, occurring as scattered solitary trees, (Plate 25). The former may reach 20 m. in height, with a generally sparse crown surmounting a stout trunk covered by light grey striped bark. *T. platyphylla* is shorter in stature, and has a dense crown of large leaves. The species *Eucalyptus papuana*, *Acacia pallida*, *Melaleuca viridiflora*, *Pandanus* sp. and *Alstonia actinophylla* K. Schum., may also be present.

This association is restricted to the deep grey or black heavy clay soils developed on the alluvial plains. These are traversed by a series of ramifying streams and are flooded during the wet season.

(f). *Pandanus sp. - Timonius Timon - Heteropogon contortus - Flaveria australasica community*

The palm, *Pandanus* sp., growing to a height of between 4 and 7 m., forms an almost pure stand of closely spaced trees along permanent or semi-permanent watercourses and springs, (Plate 26). Little or no ground storey is present, though leaf litter is prominent. Over most of the area occupied by the community, however, it occurs as a fairly open storey of low trees studding a dense growth of the tall grass, *Heteropogon contortus*.

A very open tall tree layer is generally present, dominated by the species *Timonius timon* Merrill, with *Melaleuca viridiflora* and, occasionally, *Tristania grandiflora*, *Terminalia platyphylla* and *Ficus opposita* Miq. var. *micrantha* occurring also.

Flaveria australasica Hook, a tall herb of the family

Plate 26 *Pandanus* sp. (Bulman No. 206) near Weimool Springs

Plate 27 *Imperata cylindrica* var. *major* and *Flaveria australasica* on calcareous soils with gilgai development

Plate 26 Pandanus sp. (Bulman No. 206) near Weimool Springs

Plate 27 Imperata cylindrica var. major and Flaveria australasica on calcareous soils with gilgai development

Compositae, is almost invariably present with H. contortus in the herbaceous stratum. Other species occurring include; Sorghum sp., (Bulman No. 184), Imperata cylindrica Beauv. var. major, Eragrostis japonica and the tall herb Sesbania aculeata Poir.

This community covers a fairly extensive area of fine-textured calcareous alluvium south-east of Weimool Springs. The soil has a powdery texture and, unlike the surrounding heavy clays, does not exhibit deep cracks or gilgai micro-relief.

(g). Imperata cylindrica var. major - Flaveria australasica community

This community forms a tall grassland dominated by Imperata cylindrica var. major with, however, the tall herb Flaveria australasica very common also. Apart from an occasional Timonius timon and wild fig, Ficus racemosa L., the area is devoid of trees and shrubs, (Plate 27).

This unit is restricted to small stretches of highly calcareous soil with gilgai development south-east of Weimool Springs, (Fig. 42). The gilgais are on a large scale, individual depressions being several feet across and up to 2 ft. deep. Large nodular masses of calcrete are exposed on the surface of the swells separating the depressions, (Plate 29). Where permanent water exists, the community gives way to a stand of the Pandanus sp. palm, while, as the gilgais die out, it grades into the

Plate 28 *Pipturus argenteus* thicket on calcareous soils

Plate 29 Calcrete nodules on surface of calcareous soils

Plate 28 ***Pipturus argenteus*** **thicket on calcareous soils**

Plate 29 **Calcrete nodules on surface of calcareous soils**

above community.

(h). Pipturus argenteus - Melaleuca viridiflora community

Like the last, this community is restricted to a small area of very calcareous gilgai soils south-east of Weimool Springs. Pipturus argenteus Wedd., forms a close thicket of low, many-trunked trees with a dense crown of dark green leaves, (Plate 28). It frequently supports the vine Melothria maderaspatana Cogn., while Melaleuca viridiflora occurs as scattered tall trees. The community is devoid of shrubs or herbaceous species.

On the north and west, the unit is bounded by dense stands of Pandanus sp. growing along watercourses. On the south-east, it has a fairly sharp junction with the community described above. However, dead specimens of Pipturus argenteus extend on the grassland, suggesting that the latter is expanding at the expense of the thicket. This may be related to the ravages of the buffalo which find shade under the dense foliage.

(3). Conclusions

(i). The most widespread vegetation unit occurring within the Bulman region is the sub-formation of Savanna Woodland. Structurally this unit comprises a fairly dense stratum of tall slender trees, a sparse shrub layer and a relatively close cover of tall grasses. The Savanna Woodland is generally confined to those regions of upland topography. A gradational zone of Savanna Parkland/Grassland is frequently present between these areas and the low-lying country, where Savanna Grassland is the most widespread sub-formation. Isolated thickets of the low tree, Pipturus argenteus, occur on small areas of very calcareous soils on the plains, while permanent and semi-permanent drainage lines are fringed by a dense growth of the palm, Pandanus sp.

(ii). A tall Savanna Woodland association of Erythrophleum chlorostachys - Eucalyptus ferruginea - E. tectifica - E. tetrodonta - E. jenseni - Gardenia megasperma - Chrysopogon pallidus - Andropogoneae indet., (Bulman No. 156), and the unidentified grass, Bulman No. 123, occupies the north west of the region. A deep layer of chert, veneered by acid, well-drained soils with abundant laterite nodules, gives rise to undulating country in this area.

(iii). Cochlospermum fraseri - Acacia pallida - Vetiveria elongata - Heteropogon contortus, form a distinctive community of low trees and tall grasses on rises of out-cropping dolerite. The soils, where developed, consist of pockets of loose particles of decomposing dolerite, with presumably a poor water-holding capacity.

(iv). The Gardenia megasperma - Erythrophleum chlorostachys - Vetiveria elongata - Chrysopogon pallidus community has a rather similar appearance to the last, though the low trees tend to grow slightly closer together. The unit is found on the low hills of the carbonate rocks of the Bulman Formation, where the soils are shallow and gravelly, and run-off is rapid.

(v). At the base of the hills and rises the Savanna Woodland units described above give way to a Savanna Parkland/Grassland association of _Eucalyptus tectifica_ - _E. confertiflora_ - _Hakea arborescens_ - _Heteropogon contortus_ - _Andropogoneae_ indet., (Bulman No. 156) - _Iseilema vaginiflorum_. The dominant trees are tall to mid-height and are generally widely-spaced. The herbaceous stratum consists of a fairly dense growth of tall to medium-height grasses. This unit occurs on fine-textured soils, developed on material washed down from the neighbouring higher ground.

(vi). A tall Savanna Grassland association, dominated by _Sorghum_ sp., (Bulman No. 184) - _Chionachne cyathopoda_ - _Iseilema vaginiflorum_, and with scattered trees, mainly _Terminalia platyphylla_ and _Tristania grandiflora_, is found on low-lying country subject to flooding during the wet season. The soils are deep, heavy, black clays, basic at the surface, with a gilgai micro-relief; during the dry season they are traversed by a series of wide vertical cracks.

(vii). Where the clay soils give way to looser, calcareous material lying on the drainage from limestone springs, the vegetation alters to a tall grassland community of

Heteropogon contortus, studded by the trees Pandanus sp. and Timonius timon. The tall herb Flaveria australasica is also common in this environment.

(viii). The tall grass Imperata cylindrica var. major with Flaveria australasica, occurs on a small area of the calcareous soils mentioned above. The soil exhibits gilgai development, while large masses of nodular calcrete are common on the surface.

(ix). Part of the above area is covered by a dense thicket of the low tree Pipturus argenteus. Apart from scattered individuals of the taller tree, Melaleuca viridiflora, the community is virtually devoid of other species.

(x). The distribution of the major vegetation units within the Bulman Area appears to be largely governed by edaphic and draining factors. The former encompasses both the soil reaction, which tends to become increasingly basic with decreasing elevation, and the soil depth and texture. These too are influenced by the relief, the deeper, fine-textured material generally occurring on low-lying country while shallower soils normally occupy the upland area. Both these factors have a direct bearing on the drainage status of the soil, and hence on the availability of water to the plants during the dry season.

The nature and extent of the skeletal soils on the upland regions is largely determined by the bedrock geology; both play a role in the distribution of the vegetation units. Thus each of the more widespread rock types occurring within the area is characterised by distinctive plant associations or communities.

(xi). Little is known on the lasting effects of grazing by buffalo and wild cattle on the specific composition and distribution of the vegetation units. There is some evidence, however, that this factor has caused the destruction of part of the Pipturus argenteus thicket, and has also given rise to extensive stretches of bare ground in certain areas.

SECTION H: VEGETATION DISTRIBUTION IN AREAS A AND B

(1). Introduction

The location of these areas within the Bulman region is indicated in Fig. 41. They contain the main occurrences of lead-zinc mineralisation, but although of very high grade, zinc ranging from 10 to 30% and lead from 1 to 3%, the mineralisation is confined to a total stratigraphic thickness of between 30 and 40 ft., (Sturmfels, 1952). Apart from some shallow shafts and trenches, the area has been little disturbed by mining operations.

Sturmfels, (ibid), has reported that there is a definite link between the distribution of certain plants and the outcrops of the lead-zinc mineralisation at Areas A and B. *Polycarpaea synandra* F. Muell. var. *gracilis* Benth. was noted on the mineralised zones, and, according to this author, nowhere else in the region. *Gomphrena canescens* R.Br. also grows profusely on the ore-deposits, but was observed by Sturmfels on alluvial soils remote from mineralisation. Similarly, the shrub *Tephrosia* aff. *polyzyga* F. Muell. ex Benth. was found both on the mineralised outcrops and on alluvial soils.

As a first step in determining the factors controlling the distribution of the species associated with mineralisation, the vegetation of the area was mapped on a scale of one inch to a hundred feet. A quantitative estimation of the variations in the vegetative cover within the area was obtained from a transect taken across the hill and extending on to the plain on either side. Finally, a series of plant samples was collected from the area, and analysed for copper, lead and zinc with a view to determining the relationship between metal uptake by the plants and concentrations of these metals in the underlying soil. The results of these analyses are described in Section J.

(2). Physical features and geology

The ore-deposits are situated near the summits of two low, rounded hill, rising to a height of about 40 ft. above the surrounding alluvial plain, (Fig. 43). The northern and western sides are drained by a small stream, which flows eastwards to join the Wilton River. Elsewhere, the drainage from the hill disappears in small gullies which traverse the black soil plain at the foot.

The hills are formed of limestone, dolomite and chert rocks belonging to the Bulman Formation. The beds have a roughly concentric outcrop pattern and dip gently to the south-east. These beds overlie a dolerite sill and have been affected by contact metamorphism during its intrusion. The dolomites and limestones have been altered in the following ways, (Sturmfels, 1952):-

(a). Enlargement of the grain size.

(b). Further dolomitization, (and also formation of magnesite), by selective dissolution of calcium carbonate.

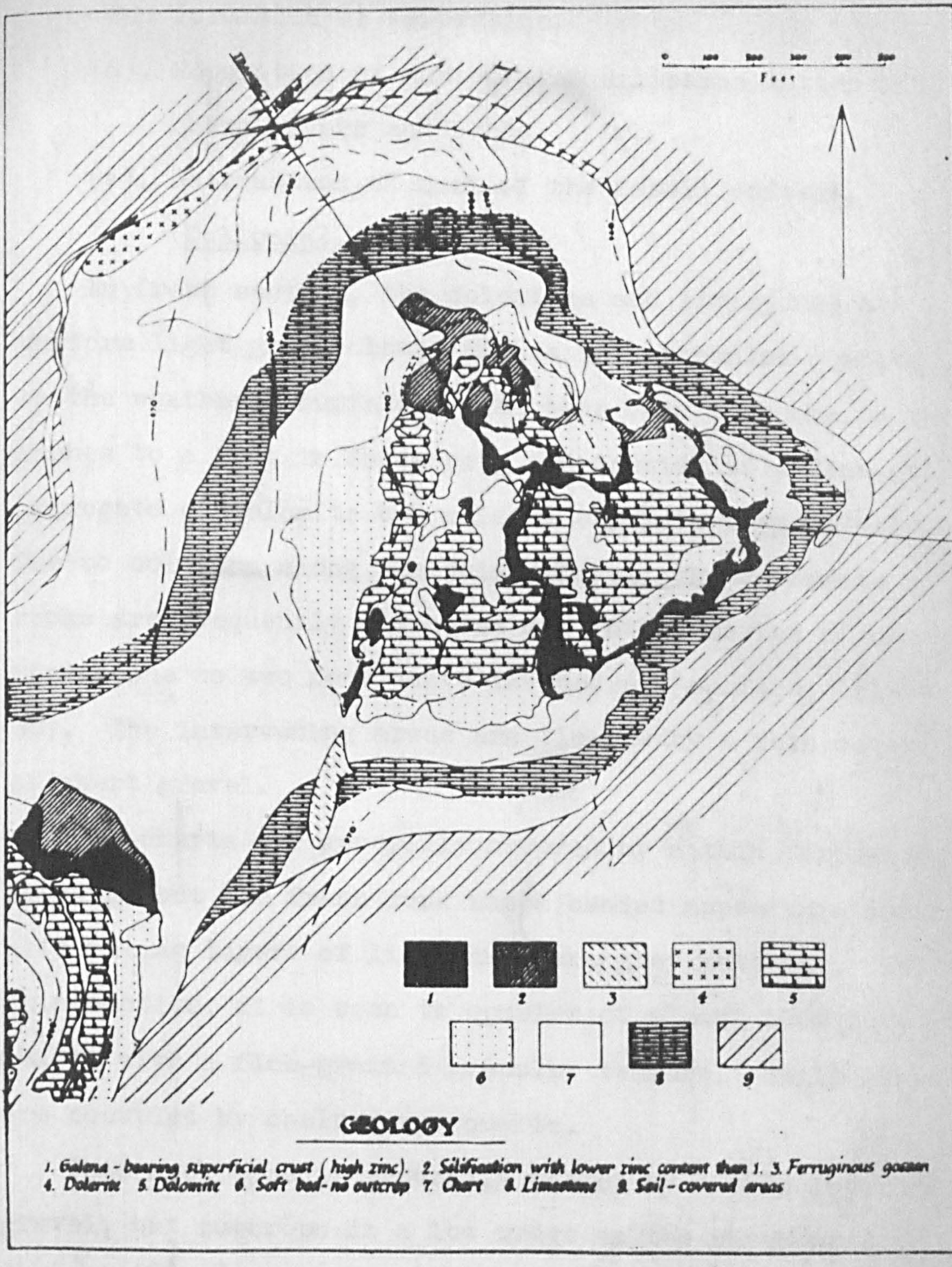


Fig. 43. Geological Map of Areas A and B, Bulman.

(c). Formation of serpentine.

(d). Separation of most of the siliceous matter into chert layers and bands.

(e). Destruction of most of the fossil content, (Collenia).

In fresh section, the dolomites and limestones are a uniform light grey colour, with a thin brownish coating on the weathered surfaces. The beds vary from one to two inches to a foot in thickness, and consist of a fine-grained aggregate of dolomite and calcite crystals respectively. Due to solution along the joint planes, the carbonate rocks are frequently weathered out into a series of blocks rising one to two feet above the bedrock surface, (Plate 30). The intervening areas are floored by a thin cover of chert gravel.

The cherts are generally covered by a thin ferruginous coating, but the fresh rock has a banded appearance due to alternating layers of light and dark grey material. In thin section, it is seen to consist of almost 100% pure quartz with a fine-grained granular texture. Small lenses are occupied by chalcedonic quartz.

This rock type is generally masked by a thin layer of gravel, but outcrops in a low ridge on the north-west side of the area.

The lead-zinc mineralisation occurring at Areas A and B has been previously described, (p.286), and only a brief

Plate 30 Weathering along joint planes in carbonate rocks, Area A, Bulman

Plate 31 Superficial mineralised crust masking ore-deposits, Area A

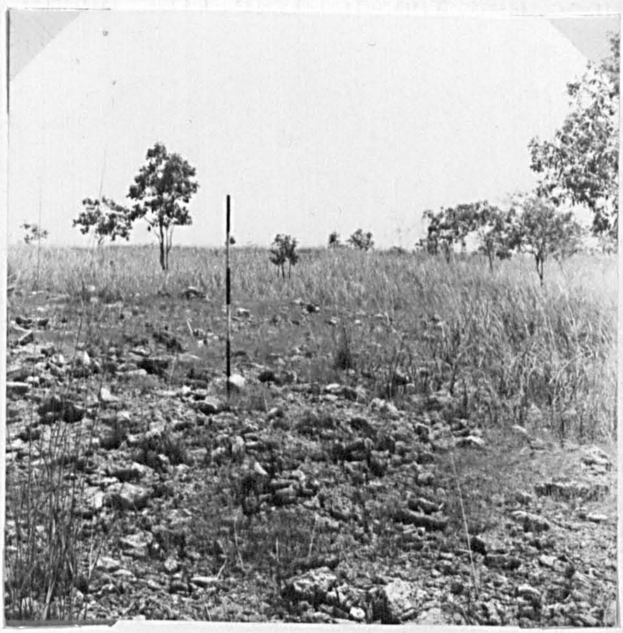


Plate 30 Weathering along joint planes in carbonate rocks, Area A, Bulman

Plate 31 Superficial mineralised crust masking ore-deposits, Area A

summary will be given here. The deposits are found in decomposed dolomite rocks and consist essentially of largely-oxidized sphalerite and partly-oxidized galena. Zinc-rich superficial crusts with solid lumps of galena mask the deposits, (Plate 31). On Area A, where the crusts are best developed, they cover quite an extensive area, although they do not appear to exceed a few feet in thickness, (Fig. 43). Two types may be distinquished; Type A as described above and a second, Type B, which contains smaller amounts of zinc and lead. One or two small ferruginous gossans are also found on the surface in Area A, but these are apparently unconnected with mineralisation.

(3). Soils

Little or no soil development has occurred on the upland parts of Areas A and B. The soils are skeletal, consisting of a few inches of gravel or rubble in a sparse reddish, fine-textured matrix. The coarser fractions are dominated by chert, even on areas underlain by carbonate rocks. The absence of fragments of this material suggests that the weathering products of the limestone and dolomite rocks have been largely removed by solution in rain-water. This is in agreement with the solution channels produced in the carbonate rocks, (Plate 30), and the acid to neutral reaction of the soils developed on the upland areas. Thus the pH of a series of samples collected from the skeletal soils ranged from 5.8 to 7.0.

The depth of soil increases at the base of the hills. The skeletal soils give way to an irregular peripheral zone, up to 200 ft. in width, of fine-textured dark-brown or grey soils with inclusions of chert rock. The pH of the surface horizons of this material ranged from 6.4 to 7.0. On the eastern side of the hill this gradational zone is absent, and the skeletal soils give way abruptly to the deep, grey or black heavy clay soils of the plains. The surface horizons of this type are basic, with a pH of about 7.8. During the rains the area occupied by these soils is flooded, and as the ensuing dry season advances the whole soil is traversed by a series of deep vertical cracks.

(4). Vegetation

(a). Tree and shrub cover

A low woodland of *Gardenia megasperma* and *Erythrophleum chlorostachys* occupies the greater part of the higher ground in Areas A and B, (Plate 32). Over the low gravelly rise separating the two hills, however, these species are joined by the taller tree *Eucalyptus confertiflora*, which is also present on smaller areas near the centre of Area A, (Fig. 44).

The deeper soils surrounding the hills are dominated by the species *Gardenia megasperma*, *Erythrophleum chlorostachys* and *Eucalyptus patellaris*. A fringing zone

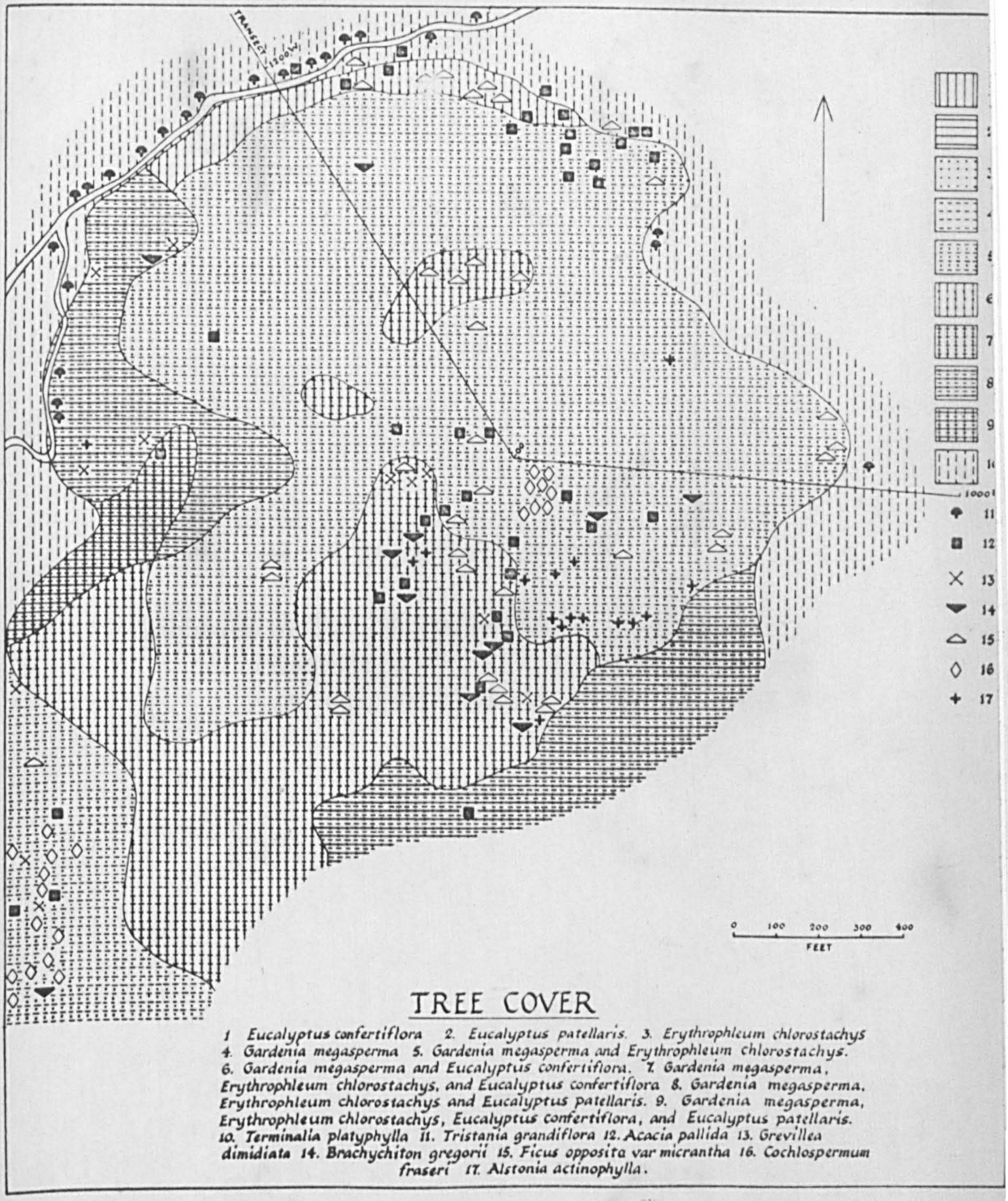


Fig. 44 Map showing Tree Cover on Areas A and B, Bulman

Plate 32 Gardenia megasperma, Vetiveria elongata and Chrysopogon pallidus on un-mineralised rocks at Area A

Plate 33 Terminalia platyphylla, Heteropogon contortus and Andropogoneae indet. (Bulman No. 156) on heavy clay soils at base of hill. Area A

Plate 32 *Gardenia megasperma*, *Vetiveria elongata* and *Chrysopogon pallidus* on un-mineralised rocks at Area A

Plate 33 *Terminalia platyphylla*, *Heteropogon contortus* and *Andropogoneae* indet. (Bulman No. 156) on heavy clay soils at base of hill. Area A

in the north is occupied by Erythrophleum chlorostachys and Eucalyptus confertiflora, while, in the west, a mixed stand of Gardenia megasperma, Erythrophleum chlorostachys, Eucalyptus confertiflora, and E. patellaris is developed over a small area.

In the north-east, this peripheral zone is absent, and the deep clay soils extend up to the base of the hill. There is thus a rapid transition from the low woodland of Gardenia megasperma and Erythrophleum chlorostachys to the grassland association of the plains. Terminalia platyphylla forms a sparse cover of tall trees over these areas, (Plate 33).

A number of other trees are present. The stream channel bordering the north-east side of the hill is lined by Tristania grandiflora. Acacia pallida has a wider distribution, occurring both on the shallow soils of the hills and on the bordering zone of deeper, fine-grained material. The low trees, Ficus opposita var. micrantha and Grevillea dimidiata, have a similar distribution. Brachychiton gregorii, Cochlospermum fraseri and the tall Alstonia actinophylla K. Schum., however, are generally restricted to the upland areas.

(b). Ground vegetation

The herbaceous stratum on the shallow gravelly soils of the hill is dominated by the species Vetiveria elongata and Chrysopogon pallidus, while Andropogoneae indet.,

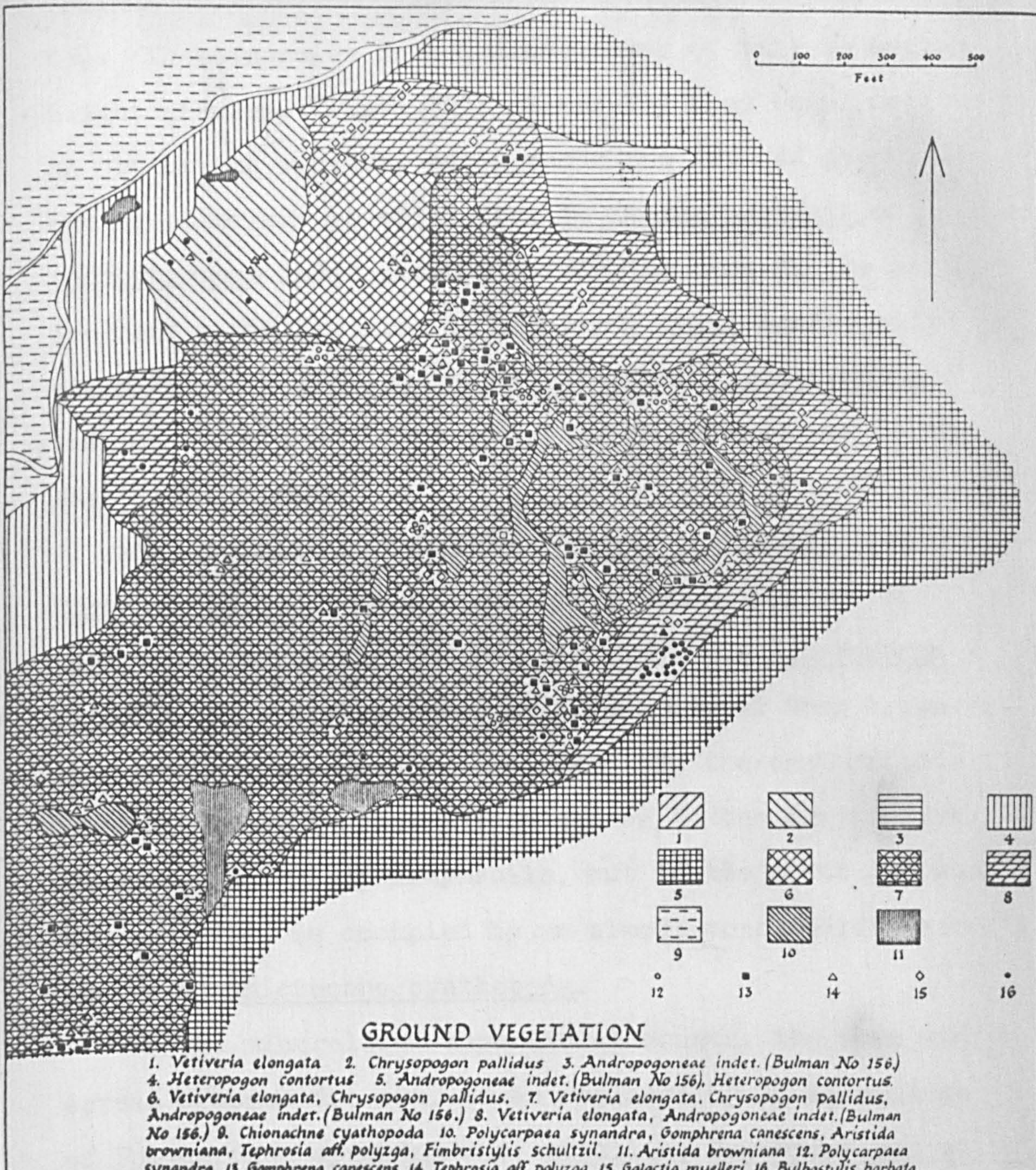


Fig. 45 Map showing Ground Vegetation on Areas A and B, Bulman

(Bulman No. 156), occupies a subdominant position, (Fig. 45). These species form a dense cover of tall to medium-height grasses, (Plate 32). Generally they occur together on the upland regions, but towards the foot of the hills one or other may go out. Thus Vetiveria elongata and Andropogoneae indet. occupy a fringing zone in the north-east and a smaller area in the west, while monospecific communities of Chrysopogon pallidus and Andropogoneae indet., cover small sectors in the north-west and north-east respectively.

At the base of the hills, Vetiveria elongata and Chrysopogon pallidus die out and a tall grassland of Andropogoneae indet., (Bulman No. 156) and Heteropogon contortus is developed on the fine-textured dark brown or grey soils which occupy this zone. On the eastern side of the hill these species extend out on to the deeper dark grey or black heavy clay soils, but in the north and west this material is occupied by an almost monospecific community of Chionachne cyathopoda.

On the mineralised superficial crusts, the more wide-spread grasses die out, to be replaced by an assemblage of Polycarpaea synandra var. gracilis, Gomphrena canescens, Aristida browniana, Tephrosia aff. polyzyga and Fimbristylis schultzii Boeck, (Plates 34,35). P. synandra var. gracilis and F. schultzii are confined to this habitat, but the other species have a wider distribution. Thus

Plate 34 *Polycarpaea synandra* var. *gracilis* on superficial mineralised crust, Area A

Plate 35 *Fimbristylis schultzii* on superficial mineralised crust, Area A

Plate 34 *Polycarpaea synandra* var. *gracilis* on superficial mineralised crust, Area A

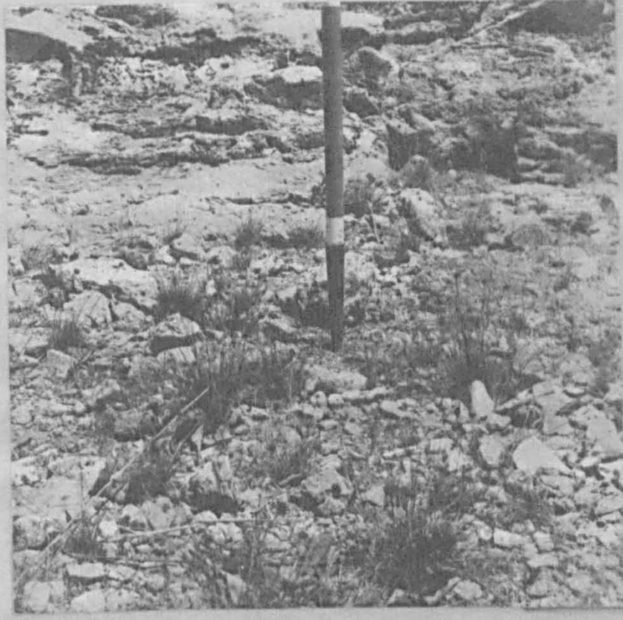


Plate 35 *Fimbristylis schultzii* on superficial mineralised crust, Area A

Gomphrena canescens and Tephrosia aff. polyzyga occur throughout the upland areas, while separate communities of Aristida browniana occupy small areas of fine-textured soil near the base of the hills.

The low creeping herb Galactia muelleri Benth. is generally restricted to regions of chert gravel or outcrop, while Bulbostylis barbata occurs sparingly on the fine-textured soils in the south-east.

(c). Discussion

The high-grade lead and zinc deposits of Areas A and B apparently have a major influence on the distribution of certain of the herbaceous plants, and possibly some of the tree and shrub species also. Otherwise, however, the variations in the bedrock geology seem to play a minor role in vegetation distribution in the area.

This is borne out by examination of the results of the transect taken across the area, (Fig. 46). Euphorbia sp., (Bulman No. 172), and Fimbristylis cardiocarpa tend to occur on areas occupied by dolomite. It is evident that the commoner species, however, such as Erythrophleum chlorostachys, Gardenia megasperma, and the grasses Vetiveria elongata and Chrysopogon pallidus, are equally abundant on areas underlain by cherts as on the carbonate rocks. As previously mentioned, the latter rock type weathers out into a series of blocks, the spaces between being floored by gravel derived from neighbouring chert

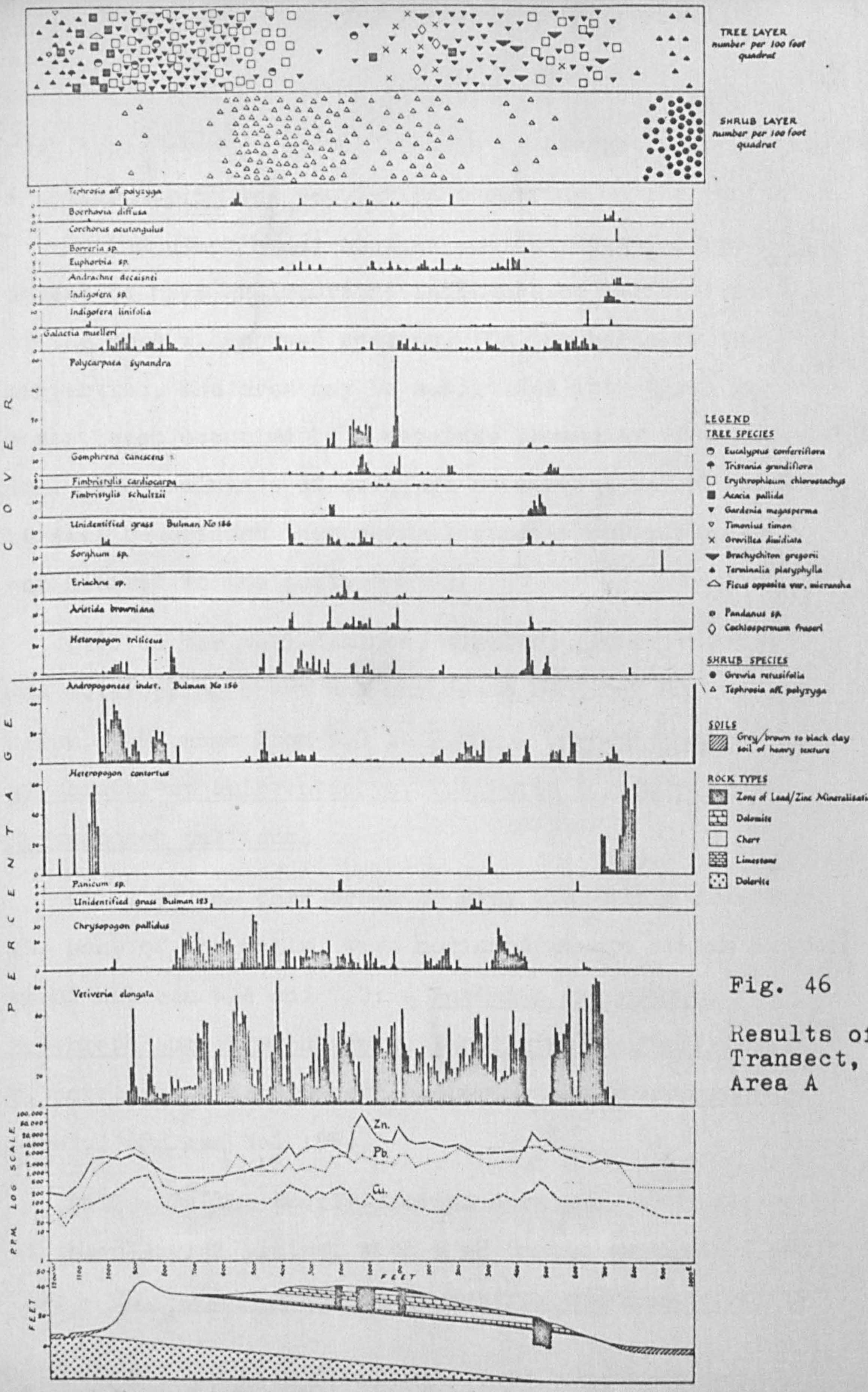


Fig. 46

Results of Transect, Area A

outcrops. Thus the soils developed over the different rock types show no strong contrast, apparently imparting a uniformity to the vegetation occurring on the two units.

On the other hand, edaphic and drainage factors appear to have an important influence on the distribution of the more widespread species. On the basis of these properties, the area may be subdivided into three environments, each occupied by a separate community or association. The dominants of each are enumerated below, where it will be evident that several species carry over from one habitat to the next.

(i). On the well-drained, shallow, gravelly soils and outcropping chert and carbonate rocks of the upland areas, (pH range from 5.8 to 7.0): - Gardenia megasperma, Erythrophleum chlorostachys, Vetiveria elongata and Chrysopogon pallidus.

(ii). On the dark brown or grey clay soils fringing the base of the hills, with medium drainage status and a pH of between 6.4 and 7.0: - Gardenia megasperma, Erythrophleum chlorostachys, Eucalyptus confertiflora, E. patellaris, Heteropogon contortus and Andropogoneae indet., (Bulman No. 156).

(iii). On the poorly-drained dark grey or black soils of the alluvial plains, with a pH on the surface of about 7.8: - Chionachne cyathopoda, Heteropogon contortus, Andropogoneae indet., (Bulman No. 156), the shrub, Grewia retusifolia, and scattered Terminalia platyphylla.

Although the presence of the ore-deposits seems to have its most marked influence on the herbaceous stratum, the transect results, (Fig. 46), suggest that the distribution of the tree species is also affected. It will be evident that the most widespread species, Erythrophleum chlorostachys and Gardenia megasperma, are virtually absent over the central part of the transect, where mineralisation is more frequent and the level of lead and zinc in the soils is consequently very high.

While frequent over the lead-zinc deposits, the shrub Tephrosia aff. polyzyga is also common on un-mineralised rocks. The transect illustrates the striking "cut-out" of the more widespread members of the herbaceous layer, however, over the surface crusts which mask the ore-deposits. Polycarpaea synandra var. gracilis and Fimbristylis schultzii show the most marked correlation with the mineralised zones. The latter was not observed elsewhere in the Bulman region, though P. synandra var. gracilis occurs over quite an extensive area on alluvial soils west of Area A, (Section J). The grasses, Aristida browniana, Eriachne sp. (Bulman No. 144), the unidentified grass, Bulman No. 186, and the herb, Gomphrena canescens, also occur on or in the vicinity of, the mineralised zones. However, these species may also be found, though generally less frequently, in areas devoid of mineralisation.

The superficial crusts overlying the lead-zinc deposits do not give rise to any marked topographic features (Plate 31), and hence the influence of relief on plant distribution in these areas can be neglected. The crusts are generally devoid of soil cover, (Plates 34,35), while the surrounding un-mineralised rocks are normally masked by a few inches of gravelly material. It is unlikely, however, that this relatively minor variation in the rooting medium can have led to the marked change in the vegetative cover over the ore-deposits. The soils of these areas, where developed, tend to be slightly more acid than those on the neighbouring rocks, (pH 6.0 to 6.4 as against 6.6 to 7.0), but again the contrast between the two habitats is low.

It is possible that other elements besides the ore-metals are enriched in the vicinity of the mineralised zones. Alternatively, the soils of these areas may be deficient in certain elements. Although the major and trace element content of the Bulman soils has not been investigated, it will be recalled that in the Dugald River Area the sole element, besides the ore-metals, which seemed to show variation in the soils over the mineralised zones was phosphorus. In these areas this showed a roughly twofold enrichment compared with the maximum on

Although growth experiments are required to explain this behaviour, it is possible that it is related to intra-specific variation within the plants. It is suggested that they have evolved ecotypes, better adapted to withstand high concentrations of the ore-metals in the rooting medium, and in their tissues, than the strains which occur in the un-mineralised regions. This may account for the occurrence of these species under such markedly contrasting environmental conditions.

(5). Conclusions

(i). The distribution of the more widespread plant species within Areas A and B is strongly influenced by variation in the depth, texture and drainage status of the soils. In turn these factors are influenced by the relief. The shallow, acid to neutral soils of the upland area support a low woodland, consisting of a relatively sparse cover of low trees but a dense ground vegetation dominated by tall grasses. The low shrub, Tephrosia aff. polyzyga, is the sole member of the shrub stratum. A narrow, intermittent, zone of Savanna Parkland/Grassland occurs on the deeper, fine-textured soils at the base of the hills. In this unit the trees are more widely spaced, but tend to be of greater stature, than in the former community, while the tall grasses generally form a sparser cover. The deep, basic, clay soils of the surrounding alluvial plain are occupied by Savanna Grassland studded by scattered tall trees.

(ii). Variations in the bedrock geology, (apart from the occurrence of the lead-zinc deposits), appear to have little affect on the distribution of the more widespread plants. This may be related to the fact that the carbonate rocks are largely veneered by a thin cover of chert gravel, similar in every respect to that overlying sub-outcropping chert bedrock. This is confirmed in part by the small variation in the pH of the skeletal soils on the upland areas. Apparently the salts leached out of the carbonate rocks by the rainwater are rapidly removed by the drainage. This lack of variation between the soils developed on the two contrasting rock types is probably the cause of the similarity of the vegetation occurring on both.

(iii). The deposits of lead-zinc ore support an assemblage comprising the herbs, *Polycarpaea synandra* var. *gracilis*, and *Gomphrena canescens*, the annual grass, *Aristida browniana*, the shrub, *Tephrosia* aff. *polyzyga* and the low sedge, *Fimbristylis schultzii*.

(iv). The distribution of *P. synandra* var. *gracilis* and *F. schultzii* shows the closest correlation with the extent of the outcropping ore-deposits. These species are confined to these sites within Areas A and B, though the former also occurs on alluvial soils containing low concentrations of the ore-metals elsewhere.

(v). While most abundant on, or in the vicinity of the mineralised zones, <u>Aristida browniana</u>, <u>Tephrosia</u> aff. <u>polyzyga</u>, and <u>Gomphrena canescens</u> are also found on barren rocks, both within and outwith Areas A and B.

(vi). Little soil development has taken place on the upland parts of Areas A and B, though the gravelly soils present on the un-mineralised rocks tend to be slightly deeper than those over the ore-deposits. In view of the minor nature of this variation, however, and the lack of contrast in relief and drainage between the mineralised and barren areas, it would appear that the excessive quantities of lead and zinc in the soils over the former zones is the dominant factor controlling plant distribution in these areas.

(vii). The species comprising the assemblage on the ore-deposits can apparently withstand very high concentrations of the ore-metals in the rooting medium without injury. It seems probable, therefore, that adaptation to these conditions is the chief distinquishing feature - in a physiological sense - between the assemblage plants and the more widespread species. Although culture experiments are required to confirm this, it is possible that the species associated with mineralisation have evolved separate ecotypes, better adapted to survival on the ore-deposits than the strains which occur in regions where the level of lead and zinc in the substrate is very much lower.

This may serve as an explanation of the fact that all these species, with the exception of Fimbristylis schultzii, were also observed in regions apparently devoid of mineralisation.

(viii). While the occurrence of the lead-zinc deposits have their most striking influence on the distribution of the ground vegetation, the high soil metal contents apparently have an effect on the tree storey also. The widespread species Erythrophleum chlorostachys and Gardenia megasperma show a marked decrease in abundance in the vicinity of the mineralised zones, suggesting that these trees are intolerant of high concentrations of lead and zinc in the rooting medium.

SECTION I: VEGETATION DISTRIBUTION IN THE WEIMOOL SPRINGS GRID AREA

(1). Introduction

The Weimool Springs Grid lies some five miles north-west of Areas A and B, (Fig. 41). The area lies astride the large Bulman Fault, which at this locality is marked by a linear depression occupied by a shallow drainage channel. The mapped area forms a rectangle 200 ft. in width, extending for 1000 ft. to the north of the channel and 400 ft. to the south, (Fig. 47).

Interest was focussed on this area because of the occurrence here of an assemblage of several species found in the vicinity of mineralisation in other parts of northern Australia. Thus one of these, Polycarpaea spirostylis, was reported as showing a distinct association with areas of copper mineralisation in eastern Queensland by Skertchley, (1897). Moreover, previous analyses of several of the assemblage species from the Weimool Springs Grid had yielded relatively high values for lead and zinc.

Details of the geology are obscured by a thick deposit of chert. This has a banded appearance due to alternating laminations of dark grey and white material. In thin section it is seen to consist of a very fine-grained interlocking aggregate of anhedral quartz crystals; slight variations in the texture impart the banded structure.

Thin parallel fissures within this material are lined by chalcedony.

The chert is interpreted as pallid zone material of a lateritic weathering profile, produced by silicification of the underlying limestone, (Section F). The nearest outcrop of this rock type is at a sink hole about half a mile to the south-east of the area. At this locality the limestone is a fine-textured grey rock with thin parallel bands of chert.

(2). Soils

Three soil types may be recognised within the area. Detrital Laterites occupy the greater part of the region to the north of the drainage channel. This soil is characterised by abundant laterite nodules and chert fragments in the upper horizons, (Plate 36 and Fig. 47C). South of the drainage line this material is absent, and here Skeletal Soils have been developed by weathering of the underlying chert. The bed of the drainage channel itself is floored by deep Alluvial Soils.

(a). Detrital Laterites

As mentioned above, this soil occurs on the gentle hill slope to the north of the drainage channel traversing the Weimool Springs Grid. Numerous laterite nodules and chert gravel make up the greater part of the profile, occurring in a sparse, loose, fine-textured matrix. On the surface this consists of a very dark grey or dark grey-

Plate 36 *Polycarpaea spirostylis*, *Trianthema rhynchocalyptra* and *Plectrachne pungens* on laterite gravel, Weimool Springs Grid, Bulman

Plate 37 Outcropping chert with *Andropogoneae* indet. (Bulman No. 135), Weimool Springs Grid

ish brown fine sand to sandy loam, giving way to a yellowish or red sandy clay loam to clay with depth. The latter has a much more compact structure than the upper layers, and in places may be cemented. A zone of mottling, comprising red and yellowish ferruginous nodules in a greyish, fine-textured material, was occasionally found near the junction with the underlying chert. The soil reaction is acid throughout, decreasing from pH 5.4 on the surface to pH 4.5 to 4.7 at the base of the profile.

This material has been classed as a detrital deposit on the evidence of the occurrence of chert fragments throughout the profile. It has apparently been derived by erosion of the ferruginous and mottled zones of an originally much deeper lateritic profile. The occurrence of similar soils in other parts of the Northern Territory has been reported by White, (1954).

No lateritic cappings were observed in the vicinity of the Weimool Springs Grid, though these have been noted several miles to the north by Campbell, (1956). It would seem that the upper ferruginous and mottled zones have been largely removed by erosion at the Weimool Springs, leaving the underlying, more resistant chert. As erosion proceeded the laterite nodules became concentrated in situ by removal of the bulk of the fine-textured material, while the traces of red and yellow mottling at the base of some of the profiles are all that remains of the original mottled zone.

Profile 1, (Plate 38), has been selected as representative of this soil type.

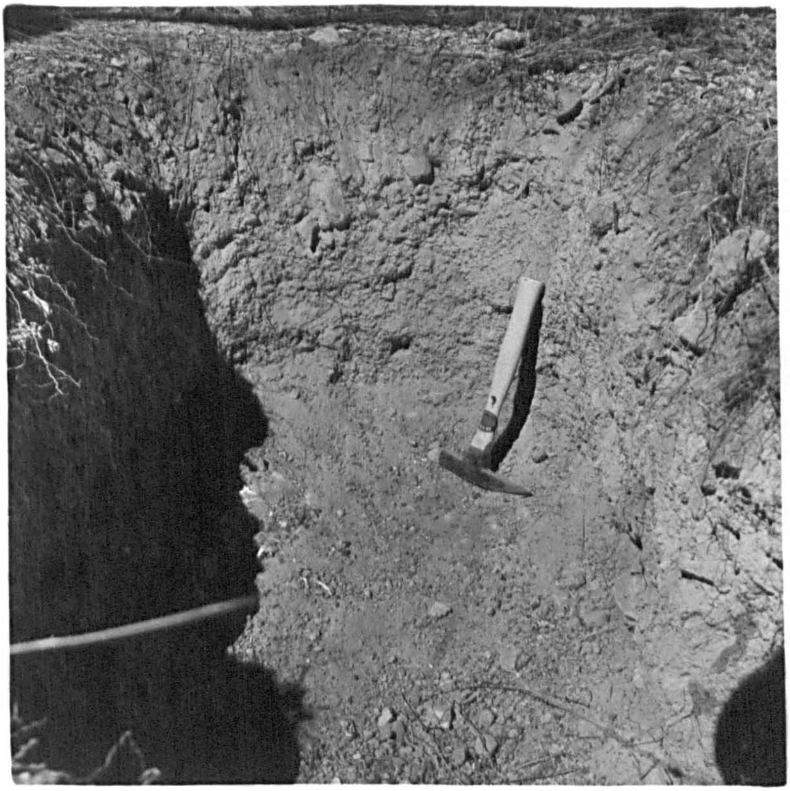
Profile 1. The pit is located at 100N/60W, (Fig. 47D), on gently sloping ground. The vegetation comprises the trees, Erythrophleum chlorostachys and Gardenia megasperma, the shrub, Petalostigma quadriloculare, and the following herbs and grasses; the unidentified grass, Bulman No. 123, Chrysopogon pallidus, Polycarpaea spirostylis and Trianthema rhynchocalyptra F. Muell.

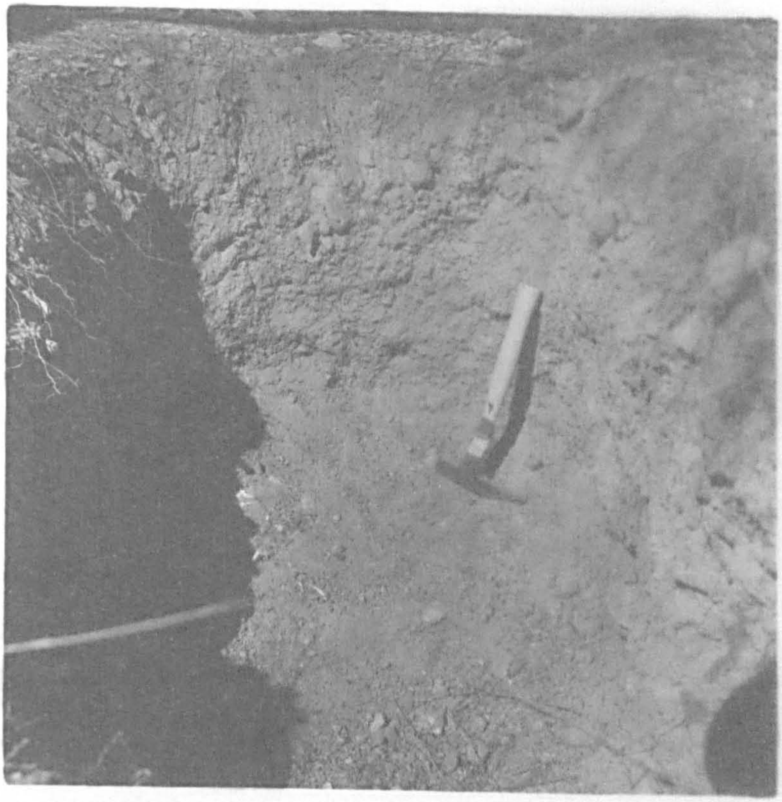
Profile Description

0 - 4 ins. :- Very dark grey 10YR 3/1 fine sand with laterite and chert gravel comprising 70% of the whole; the laterite nodules are rounded, generally 1/8 to 1/4 in. in diam.; the chert fragments are subangular, normally 3/4 to 1 in. across, up to 2 by 3 ins., with a light ferruginous coating. The horizon is loose and un-cemented. pH 5.4

4 - 26 ins. :- Greyish brown 10 YR 5/2 fine sand with abundant laterite nodules, generally 1/6 in. in diam., and subangular chert fragments up to 3 ins. across; the gravel forms approximately 80% of the horizon, which is loose and un-cemented.

Plate 38 Profiles through Detrital Laterite,
Weimool Springs Grid





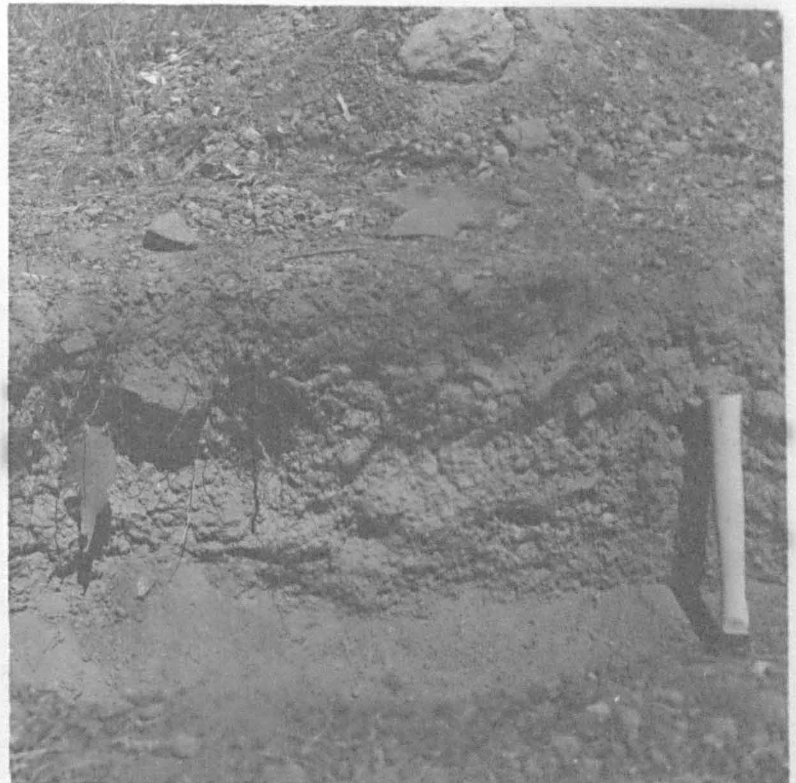


Plate 38 Profiles through Detrital Laterite,
Weimool Springs Grid

	4 - 12 ins.	pH 4.2
	12 - 26 ins.	pH 4.6
26 -32 ins. :-	Cemented, mottled, red, yellow and grey material, consisting of red and yellow ferruginous nodules in a fine-textured grey matrix; large chert fragments occur at the base.	pH 4.7

(b). Skeletal Soils

The Detrital Laterites are absent from the areas south of the drainage channel traversing the Weimool Springs Grid. Presumably in this region they have been removed by increased erosion compared with the area to the north.

The soils developed on the underlying chert, which is frequently exposed on the surface as low, rounded outcrops, (Plate 37), consists of reddish, fine-textured material with numerous chert fragments. The latter have a rotted appearance and are coated with bright red ferruginous material.

On surface the matrix is a reddish brown sandy clay loam, giving way to a red clay with depth. The soil reaction is acid throughout.

These soils have apparently been produced by weathering of the underlying chert. As witnessed by the decrease in grain size and deepening of the reddish colouration with depth, some eluviation of clay minerals and iron oxide has occurred. The general lack of profile development, however, warrants these soils being classed as skeletal.

Profile 4, (Plate 39), was sited on representative material.

Profile 4. The pit is located at 250S/10E, (Fig. 47D), on a gentle slope to the north. The vegetation comprises the trees, Eucalyptus tectifica and Erythrophleum chlorostachys, and the grasses Chrysopogon pallidus and Andropogoneae indet., (Bulman No. 156).

Profile Description

0 - 5 ins. :- Dark reddish brown 2.5 YR 4/6 clay with fragments of ferruginous chert up to 1 by 1½ ins. across, forming approximately 50% of the whole pH 6.1

5 -38 ins. :- Red 2.5 YR 4/6 clay with nodular texture; the nodules have an average diameter of 1/8 in., and consist of small fragments of dark red ferruginous chert; larger chert fragments up to 2 by 7 ins. across are also common.

5 - 14 ins. pH 5.6 14 - 22 ins. pH 5.6

22- 31 ins. pH 5.8 31 - 38 ins. pH 6.0

(c) Alluvial Soils

The drainage channel is floored by a uniform dark reddish brown structureless sandy clay loam. Fragments of chert, and occasionally ferruginous grit, occur throughout the profile, but laterite nodules are rare. The full depth of this material is unknown, the pit sunk in the channel terminating at 41 ins.

Profile 3, (Plate 40), was taken near the centre of the drainage line.

Profile 3. The pit is located at 155S/30W. The trees, Eucalyptus tectifica and Erythrophleum chlorostachys, dominate the tree storey, while the tall grasses, Heteropogon contortus and Andropogoneae indet., (Bulman No. 156), are virtually the sole members of the ground vegetation.

Profile Description

0 - 6 ins. :- Dark reddish brown 5 YR 3/4 sandy clay loam, structureless, with scattered chert fragments, generally ½ to 1 in. across, subangular, with ferruginous coating.

pH 6.2

6 -41 ins. :- Dark reddish brown 2.5 YR 3/4 sandy clay loam, structureless, with subangular chert fragments with ferruginous coating, up to 3 by 4 ins. across; occasional subrounded fragments of ferruginous grit, comprising small angular chert fragments in a medium-grained matrix of rounded quartz crystals with a haematite cement.

Plate 39 Profile through Skeletal Soil on chert, Weimool Springs Grid

Plate 40 Profile through alluvium of drainage channel, Weimool Springs Grid

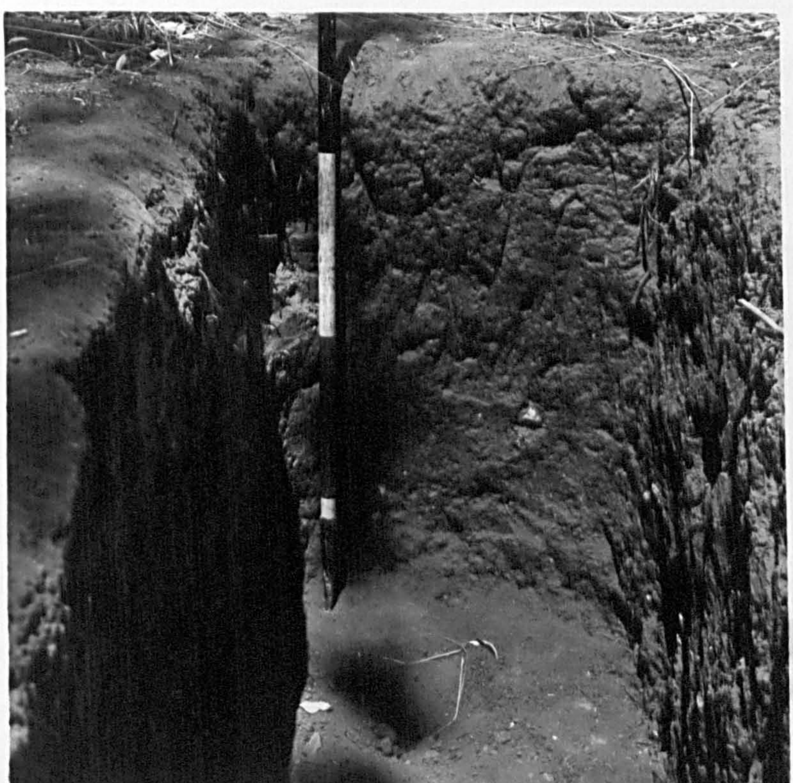


Plate 39 Profile through Skeletal Soil on chert, Weimool Springs Grid

Plate 40 Profile through alluvium of drainage channel, Weimool Springs Grid

6 - 20 ins. pH 5.5 20 - 32 ins. pH 5.4

32- 41 ins. pH 5.4

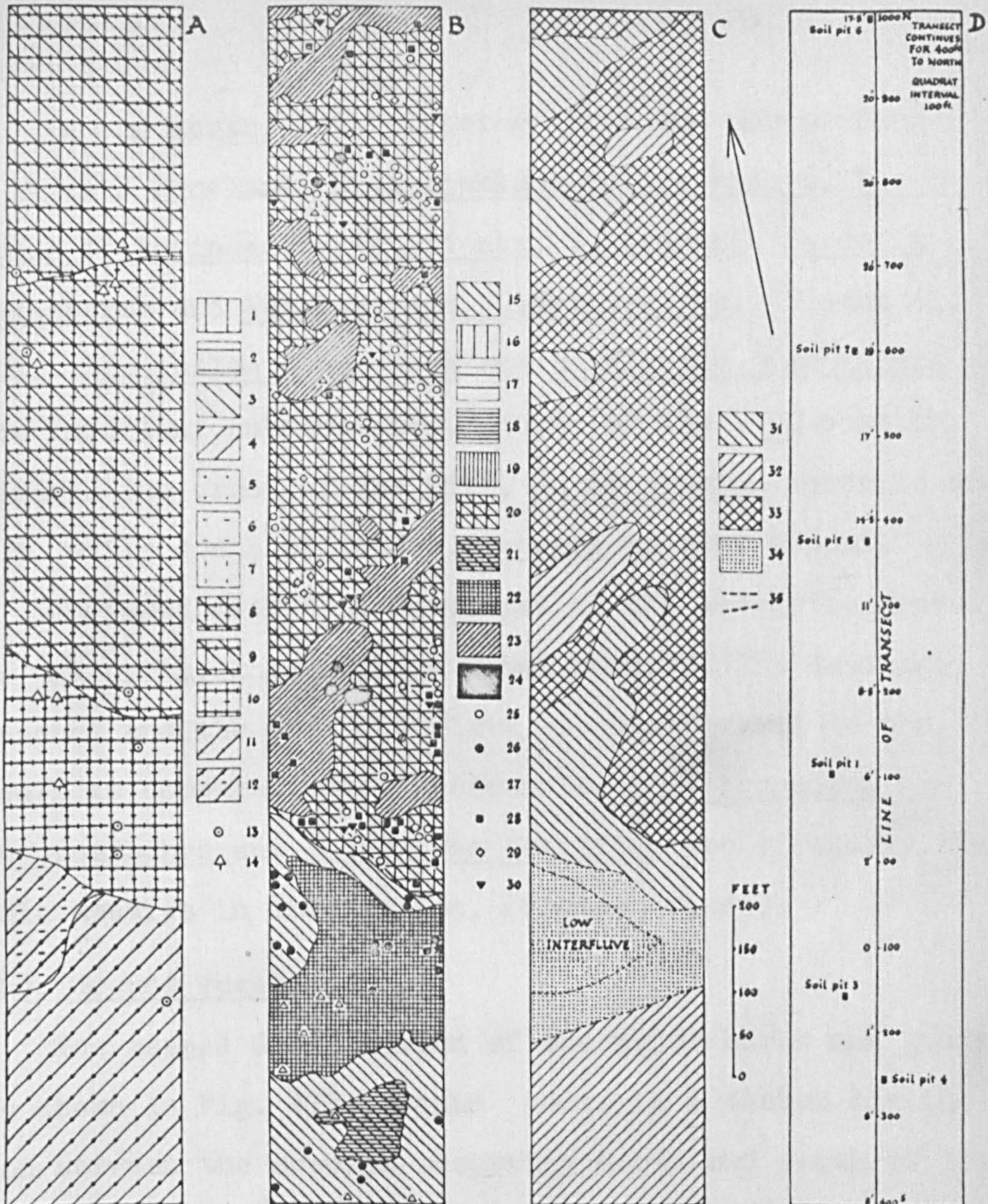
(3). Vegetation

As indicated on the regional vegetation map, the Weimool Springs Grid is occupied by an association of *Erythrophleum chlorostachys*, *Eucalyptus ferruginea*, *E. tectifica*, *E. tetrodonta*, *E. jenseni*, *Gardenia megasperma*, *Chrysopogon pallidus*, *Andropogoneae* indet., (Bulman No. 156), and the unidentified grass, Bulman No. 123. These species form a Savanna Woodland, comprising a fairly dense upper storey of tall trees, sparse low tree and shrub layers, and a relatively dense cover of tall perennial grasses and annual and perennial herbs. In spite of the comparatively close spacing of the trees, the sparse nature of their foliage allows ample light to penetrate to the ground vegetation, (Plates 41, 42).

The detailed investigations made within the Weimool Springs Grid indicates, however, that wide variations take place in the specific composition of this association. These variations are discussed below.

(a). Tree and shrub cover

Examination of the map of the distribution of the more widespread trees and shrubs, (Fig. 47A), indicates that a marked variation in these strata occurs between the area occupied by mixed laterite and chert gravel to the north of the drainage channel, and the bed of the channel and



A. TREE & SHRUB COVER 1. *Eucalyptus ferruginea*. 2. *E. tetrodonta*. 3. *E. jenseni*. 4. *E. tectifica* 5. *Erythrophleum chlorostachys*. 6. *Gardenia megasperma*. 7. *Petalostigma quadriloculare*. 8. *Erythrophleum chlorostachys, Eucalyptus ferruginea, E. tetrodonta, E. jenseni, Gardenia megasperma, Petalostigma quadriloculare*. 9. *Erythrophleum chlorostachys, Eucalyptus ferruginea, E. tetrodonta, E. jenseni, Petalostigma quadriloculare*. 10. *Erythrophleum chlorostachys, Eucalyptus ferruginea, E. tetrodonta, Gardenia megasperma, Petalostigma quadriloculare*. 11. *Erythrophleum chlorostachys, Eucalyptus tectifica*. 12. *Erythrophleum chlorostachys, Eucalyptus tectifica, Gardenia megasperma*. 13. *Eucalyptus grandifolia*. 14. *Terminalia pterocarpa*.

B. GROUND VEGETATION 15. *Chrysopogon pallidus*. 16. Unidentified grass, (Bulman No 123.) 17. *Andropogoneae* indet., (Bulman No.135) 18. *Andropogoneae* indet., (Bulman No 156.) 19. *Heteropogon contortus*. 20. *Chrysopon pallidus*, unidentified grass, (Bulman No 123.) *Andropogoneae* indet., 21. *Chrysopogon pallidus, Andropogoneae* indet., (Bulman No 156.) 22. *Andropogoneae* indet., (Bulman No 156.) *Heteropogon contortus*. 23. *Polycarpaea spirostyles*, Unidentified grass., (Bulman No 123.) *Trianthema rhynchocalyptra* assemblage. 24. *Plectrachne pungens* 25. *Polycarpaea spirostyles*. 26. *Polycarpaea corymbosa* 27. *Tephrosia* aff. *polyzyga* 28. *Gomphrena canescens*. 29. *Galactia muelleri*. 30. *Trianthema rhynchocalyptra*

C. SURFACE CHARACTERISTICS. 31. Laterite gravel. 32. Chert gravel. 33. Laterite and chert gravel in variable proportions. 34. Fine alluvium. 35. Wash area.

Fig. 47 A,B,C,D Maps of (A) Tree and Shrub Cover, (B) Ground Vegetation, (C) Surface Characteristics and (D) Location of Transect, Soil Pits, in the Weimool Springs Grid chert gravel to the south.

In the north, the following trees and shrubs form a layered woodland; Erythrophleum chlorostachys, Eucalyptus ferruginea, E. tetrodonta, E. jenseni, Gardenia megasperma and Petalostigma quadriloculare, (Plates 41, 42). Terminalia pterocarya and Eucalyptus grandiflora are important subdominants. North of the 700N station, towards the crest of the hill, G. megasperma tends to die out, while south of 200N E. jenseni is also absent.

Compared with that developed on the lateritic gravel to the north, the woodland which occupies the drainage channel and the area underlain by chert gravel to the south is comparatively depauperate. Erythrophleum chlorostachys and Eucalyptus tectifica are virtually the sole species in this region, (Plates 43, 44).

(b). Ground vegetation

The mapped distribution of the major herbs and grasses is shown in Fig. 47B. Again there is a marked distinction between the species occurring north and south of the channel, while the channel itself is occupied by a separate assemblage.

In the north, the dominant species comprise Chrysopogon pallidus, the unidentified grass, Bulman No. 123, and Andropogoneae indet., (Bulman No. 135). These form a fairly dense growth of tall to medium height tussock grasses. The intervening spaces are occupied by a number of

Plate 4I <u>Eucalyptus jenseni</u>, <u>Erythrophleum chlorostachys</u>, <u>Terminalia pterocarya</u> on Detrital Laterites, Weimool Springs Grid

Plate 42 <u>Eucalyptus tetrodonta</u>, <u>E. ferruginea</u> on Detrital Laterites, Weimool Springs Grid

Plate 41 *Eucalyptus jenseni*, *Erythrophleum chlorostachys*, *Terminalia pterocarya* on Detrital Laterites, Weimool Springs Grid

Plate 42 *Eucalyptus tetrodonta*, *E. ferruginea* on Detrital Laterites, Weimool Springs Grid

herbs, including Polycarpaea spirostylis, Gomphrena canescens, Galactia muelleri and Trianthema rhynchocalyptra. The grasses Plectrachne pungens (R.Br.) C.F. Hubbard and Aristida browniana form separate communities in places.

Areas where laterite gravel predominates in the surface soil carry an assemblage of Polycarpaea spirostylis, the unidentified grass, Bulman No. 123, and Trianthema rhynchocalyptra, (Plate 36).

The bed of the drainage channel is occupied by a tall grassland of Heteropogon contortus and Andropogoneae indet (Bulman No. 156), (Plate 43). The latter species also occurs over part of the area occupied by chert gravel south of the channel. However, over most of this sector, and in a fringing zone north of the channel, Chrysopogon pallidus forms the sole dominant.

The low shrub Tephrosia aff. polyzyga occurs to a limited extent throughout the area, but is most frequent in the bed of the channel. Polycarpaea corymbosa has a rather similar distribution.

(c). Discussion

A more detailed picture of the changes in the vegetation of the Weimool Springs Grid may be obtained from examination of the results of the transect taken in the area. This runs in a roughly north-south direction along the centre of the Grid, and extends for a further 400 ft.

Plate 43 *Eucalyptus tectifica*, *Heteropogon contortus* and *Andropogoneae* indet. (Bulman No. I56) along drainage channel, Weimool Springs Grid

Plate 44 *Eucalyptus tectifica*, *Erythrophleum chlorostachys*, *Chrysopogon pallidus* and *Andropogoneae* indet. (Bulman No. I56) on Skeletal Soils on chert, Weimool Springs Grid

Plate 43 Eucalyptus tectifica, Heteropogon contortus and Andropogoneae indet. (Bulman No. I56) along drainage channel, Weimool Springs Grid

Plate 44 Eucalyptus tectifica, Erythrophleum chlorostachys, Chrysopogon pallidus and Andropogoneae indet. (Bulman No. I56) on Skeletal Soils on chert, Weimool Springs Grid

to the north, (Fig. 47D).

The data recorded on the transect, (Fig. 48), strongly suggest that the changes in the tree, shrub and herbaceous strata are related to variations in the soil and drainage conditions. Four subdivisions of the major association, each of them characteristic of different habitats as defined by these properties, may be recognised.

(i). On the chert rubble and outcrop, with excessive drainage, north of the 1000N station; _Erythrophleum chlorostachys_, _Eucalyptus tetrodonta_, _Terminalia pterocarya_, _Petalostigma quadriloculare_, _Tephrosia_ sp. (Bulman No. 118), _Chrysopogon pallidus_ and _Galactia muelleri_.

(ii). On the well-drained Detrital Laterites north of the drainage channel; _Erythrophleum chlorostachys_, _Eucalyptus ferruginea_, _E. tetrodonta_, _E. jenseni_, _Gardenia megasperma_, _Petalostigma quadriloculare_, _Andropogoneae_ indet., (Bulman No. 135), and the unidentified grass, Bulman No. 123.

(iii). On the poorly-drained sandy clay loam soils of the drainage channel; _Erythrophleum chlorostachys_, _Eucalyptus tectifica_, _Andropogoneae_ indet., (Bulman No. 156), and _Heteropogon contortus_.

(iv). On the relatively poorly-drained clay soils developed on the chert south of the drainage channel; _Erythrophleum chlorostachys_, _Eucalyptus tectifica_, _Andropogoneae_ indet., (Bulman No. 156), and _Chrysopogon pallidus_

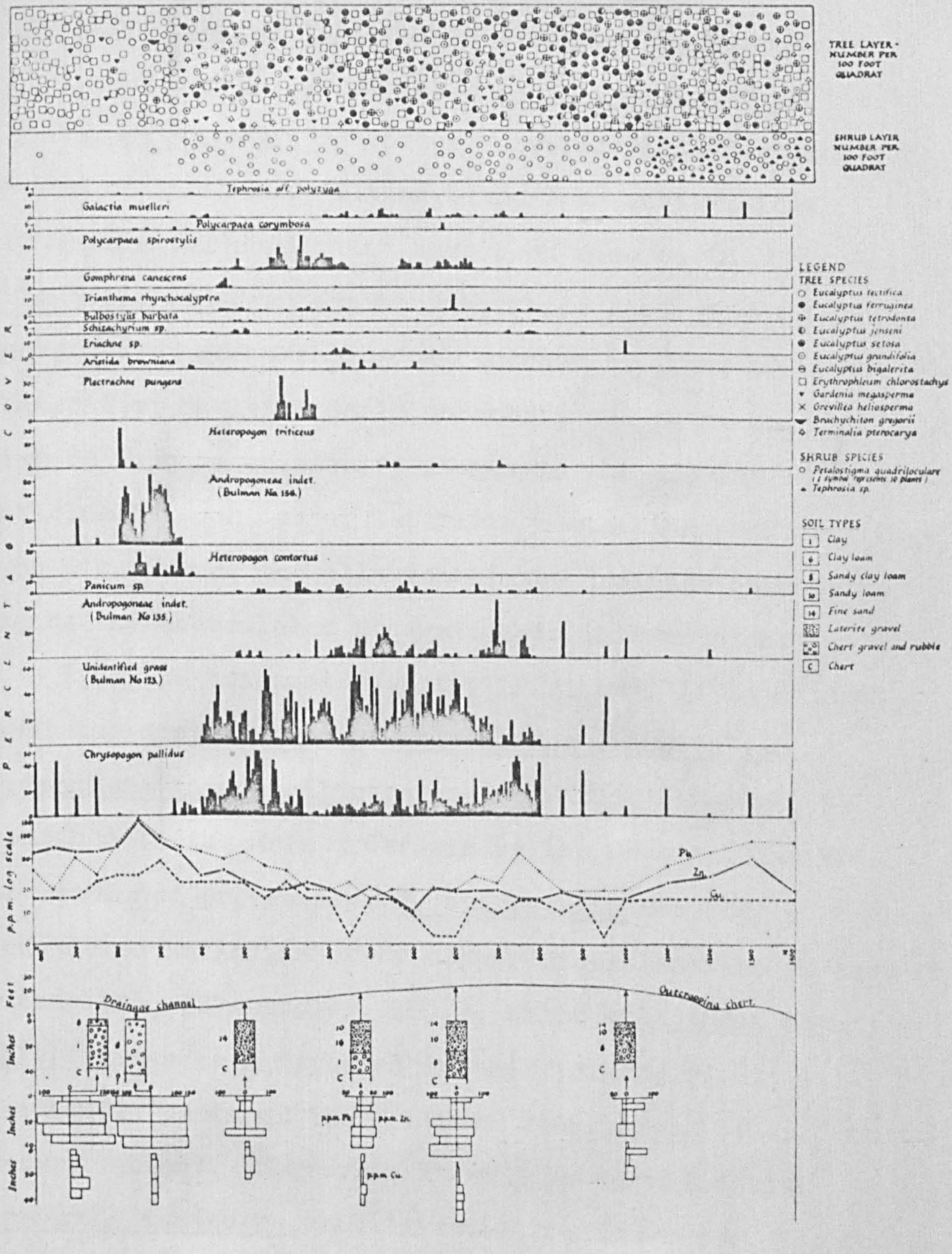


Fig. 48 Results of Transect, Weimool Springs Grid

It is apparent that certain species, typified by _Erythrophleum chlorostachys_, are found throughout the area, while others, such as _Eucalyptus jenseni_ or the grass, _Heteropogon contortus_, are restricted to a narrow range of habitats. Although the four subdivisions of the environmental conditions have been made on the basis of the soils and drainage status, these factors are in turn governed by geomorphological processes. Thus the Detrital Laterites, Skeletal Soils on chert, and outcropping chert, may be seen as successive stages in the erosion of an originally much deeper lateritic weathering profile. On the other hand, the alluvium of the drainage channel represents the accumulated products from this erosion.

From the transect results, (Fig. 48), it is evident that the distribution of _Polycarpaea spirostylis_, _Trianthema rhynchocalyptra_ and _Gomphrena canescens_ is confined to the area underlain by the Detrital Laterite. As mentioned previously, _P. spirostylis_ has long been considered an indicator of copper mineralisation in eastern Queensland, (Skertchley, 1897), while _Trianthema rhynchocalyptra_ has been reported in the vicinity of mineralisation in parts of the Northern Territory, (Cole, personal communication). Moreover, it will be recalled that _Gomphrena canescens_, and likewise the low shrub, _Tephrosia_ aff. _polyzyga_, are common on the outcropping lead-zinc deposits at Areas A and B, though also occurring on un-mineralised rocks in these areas.

The geochemical data, however, seems to rule out the possibility of these species being associated with, at least, near-surface mineralisation in the Weimool Springs Grid Area, (Fig. 48). Although the tenor of lead and zinc increases in the near-surface alluvium of the drainage channel, the level of enrichment, (150 ppm), is still of a comparatively low order. Relatively high values for these elements also occur in the Skeletal Soils on the chert south of the wash area, and over the region of chert outcrop at the northern end of the transect. On the other hand, the surface horizons of the Detrital Laterites, where P. spirostylis, G. canescens and T. rhynchocalyptra are most abundant, show the lowest values for all three metals.

Moreover, analysis of the profile samples indicates little marked variation between the metal content in the surface soil layers and that of the deeper horizons. It is true that both lead and zinc show a minor increase with depth in the profile through the lateritic gravel at 100N, but similar gradients are absent in the remainder of the profiles through this zone. The metal content in the alluvium of the drainage channel remains relatively constant with depth, while the profile through the Skeletal Soil on cherts to the south shows only a minor rise in the zinc content in the deeper soil layers.

The distribution of Tephrosia aff. polyzyga and Gomphrena canescens at Areas A and B indicates that these species can grow equally well on the mineralised surface crusts as on barren rocks, suggesting that their occurrence in the Weimool Springs Grid Area is probably not significant as regards the possibility of underlying mineralisation. As mentioned previously, the species P. spirostylis and T. rhynchocalyptra tend to congregate on the pockets of lateritic gravel within the area occupied by the Detrital Laterites. It would seem, therefore, that these species represent a variation of the normal ground vegetation in response to the high proportion of laterite nodules in the near-surface soil horizons. Possibly the higher iron content of these soils is the controlling factor governing this alteration in the herbaceous stratum, but this requires further investigation.

However, in spite of the low order of the ore-metal enrichment in the soils of this area, the possibility remains that mineralisation is present in the underlying rocks. As will be discussed in the following section, several of the plant samples collected from the Grid contained relatively high lead and zinc contents. Secondly, assuming mineralisation were present in the bedrock, its presence might not be reflected in the surface soil horizons due to the thick chert deposit. And thirdly, the higher metal contents found in the alluvium of the drainage channel possibly indicate that lead and zinc are being fed into the drainage from outcropping or sub-outcropping mineralisation further upstream. Until further studies have been made in this region, however, the significance of these observations cannot be fully elucidated.

(4). Conclusions

(i). The most widespread vegetation unit occurring in the Weimool Springs Grid Area is that developed on the Detrital Laterites. The vegetation developed on these acid, well-drained soils comprises numerous tree species, of which Erythrophleum chlorostachys, Eucalyptus jenseni, E. tetrodonta and Gardenia megasperma are the most important. The low Petalostigma quadriloculare is the sole member of the shrub stratum, while the tall to medium height grasses, Andropogoneae indet., (Bulman No. 135), Chrysopogon pallidus and the unidentified grass, Bulman No. 123, dominate the ground vegetation.

(ii). Relatively poorly-drained acid clay soils with abundant chert inclusions have been developed on the underlying cherts where the lateritic gravel has been removed by erosion. These regions are occupied by a depauperate vegetation of Erythrophleum chlorostachys, Eucalyptus tectifica, Andropogoneae indet., (Bulman No, 156), and Chrysopogon pallidus.

(iii). Where the chert comes to the surface, as on the steeper ground in the north of the area, the characteristic vegetation consists of the species, *Erythrophleum chlorostachys*, *Eucalyptus tetrodonta*, *Terminalia pterocarya*, *Petalostigma quadriloculare*, *Tephrosia* sp. (Bulman No. 118), *Chrysopogon pallidus* and the herb, *Galactia muelleri*.

(iv). The shallow drainage channel traversing the area is occupied by the trees, *Erythrophleum chlorostachys* and *Eucalyptus tectifica*, and the grasses, *Andropogoneae* indet., (Bulman No. 156), and *Heteropogon contortus*.

(v). Regions where the surface soil horizons are dominated by laterite nodules are generally occupied by a distinctive assemblage of herb and grass species. These comprise *Polycarpaea spirostylis*, *Trianthema rhynchocalyptra* and the unidentified grass, Bulman No. 123. The normally widespread grasses, *Chrysopogon pallidus* and *Andropogoneae* indet., (Bulman No. 156), show a corresponding decrease in abundance in these areas.

(vi). Although *P. spirostylis* and *T. rhynchocalyptra* have been observed over ore-deposits in other regions of northern Australia, and *Tephrosia* aff. *polyzyga* and *Gomphre* *canescens* occur on lead-zinc mineralisation in the Bulman Area, their occurrence in the Weimool Springs Grid is apparently unrelated to near-surface mineralisation. It is possible, however, that the relatively high concentrations of lead and zinc in the alluvium of the drainage channel is related to mineralisation somewhere in the vicinity, but this requires further investigation.

(vii). There seems little doubt that the variations in the vegetative cover occurring within the Weimool Springs Grid Area, both on a large scale and as regards the minor changes in the ground vegetation, are governed by edaphic and drainage factors. The various vegetation groupings described above are each characteristic, (though there is much species carry-over from one group to the next), of sites differing in soil depth, texture and drainage status. Neglecting the alluvium of the drainage channel, these various sites represent stages in the stripping of the former lateritic weathering profile which once occupied the region. These stages are Detrital Laterites derived from the ferruginous zone, Skeletal Soils developed on weathered pallid zone material, (chert), and stripped pallid zone. Hence long-term geomorphological processes also have a bearing on vegetation distribution in this area.

SECTION J: BIOGEOCHEMICAL INVESTIGATIONS IN THE BULMAN AREA

(1). Introduction

Biogeochemical investigations in the Bulman Area were more limited in scope than those at the Dugald River. Sampling was generally restricted to those species associated with the lead-zinc mineralisation in the area, or which had been reported in the vicinity of mineralisation in other regions. As in the Dugald River Area, the plants were analysed for copper, lead and zinc.

The primary aims of the investigations were twofold, i.e.:-

(i). To investigate the relationships between the copper, lead and zinc contents in the plants and the concentrations of these metals in the soils overlying mineralisation, with a view to determining the factors governing plant distribution in these areas.

(ii). To investigate whether the species associated with mineralisation in the Bulman Region, and those reported in the vicinity of mineralisation in other areas, contained anomalous concentrations of copper, lead and zinc when growing in areas not known to be mineralised.

The physiological processes involved in the absorption of metals by plants, the literature on biogeochemical methods and the analytical methods and presentation of results have been discussed on pp. 185 - 192.

Seven samples of herbaceous species and one sample of the shrub, Tephrosia aff. polyzyga, were collected from Area A, the main occurrence of lead-zinc mineralisation within the Bulman region. In the Weimool Springs Grid Area six herbaceous species have been sampled and a further sample of Tephrosia aff. polyzyga analysed. - Finally, three herbs were collected from areas not known to be mineralised. The results from these three groups of samples will be described in turn.

(2). Plant analyses from Area A

In agreement with the relative proportions of zinc, lead and copper in the ore-deposits and overlying soils of this area, the plants contain decreasing quantities of these metals in the order named, (Table 30).

The level of zinc in the plants ranges from 1500 to 135,000 (167.1 to 13,500) ppm compared with a range of 600 to 85,000 ppm in the underlying soils.[x] The highest values within the aerial parts of the plants occur either in the leaves or the stems.

In the case of lead, the results of analyses of the

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[x]Footnote:- As in the Dugald River Area, the results of the plant analyses are given first as the metal content in parts per million of the ash, followed, (in parenthesis) by the metal content in ppm of the oven-dry material.

The results for soil analysis refer to minus 80 mesh samples collected at a depth of 6 to 8 inches.

Table 30 : Miscellaneous Species. Analyses of Plant Samples from Area A, Bulman.
Un-milled, dry-ashed Material.

No.	Species	Station on Transect/ Location	Part of Plant	% Ash	ppm of ash			Cu/Zn Ratio	ppm of oven-dry material			ppm of soil (6-8 ins)			Cu/Zn Ratio	Rock Type
					Cu	Pb	Zn		Cu	Pb	Zn	Cu	Pb	Zn		
41/48	Fimbristylis schultzii	475^{E}	Flowers	9.06	40	2400	6750	0.006	3.62	217	611	475	6800	12500	0.038	Mineralised superficial crust
			Leaves	8.25	25	6000	17500	0.001	2.06	495	1444					
			Stems	5.89	50	1200	16250	0.003	2.94	70	957					
41/61	Bulbostylis barbata	Base of hill - SE side	Flowers	11.14	65	170	1500	0.042	7.01	18.61	167	170	2100	4800	0.035	Chert- on drainage from dump
			Stems	4.98	300	750	16000	0.019	13.20	33.00	704					
41/49	Polycarpaea synandra var. gracilis	00 pt.	Flowers	4.98	55	1400	26500	0.002	2.73	70	1320	200	3200	31000	0.006	Mineralised superficial crust
			Stems	2.95	100	8000	68000	0.002	2.95	236	2006					
41/50	Aristida browniana	00 pt.	Stems	5.58	27.5	2200	9500	0.003	1.53	122	530	200	3200	31000	0.006	"
41/54	Tephrosia aff. polyzyga	00 pt.	Stems	2.17	115	1300	11500	0.01	2.50	28.21	250	200	3200	31000	0.006	"
41/51	Euphorbia sp., (No.172)	50^{W}	Leaves	11.80	22.5	85	10500	0.002	2.65	10.03	1240	100	2200	11000	0.009	Dolomite
			Stems	6.70	45	1200	25000	0.002	2.01	80	1675					
41/52	Gomphrena canescens	125^{W}	Flowers	6.83	30	480	32500	0.0009	2.05	32.78	2220	80	3400	85000	0.0009	Mineralised superficial crust
			Leaves	10.00	25	700	135000	0.0002	2.50	70	13500					
41/58	Galactia muelleri	775^{W}	Stems	2.74	60	1200	55000	0.001	1.64	32.88	1507	70	300	900	0.076	Chert
			Leaves	13.74	50	240	4500	0.011	6.87	32.97	618					
			Stems	4.98	75	375	3700	0.02	3.73	18.67	184					

plants range from 85 to 8000, (10.03 to 495) ppm while the lead content in the underlying soils ranges from 235 to 6800 ppm. Again the highest values are found either in the leaves or stems.

Evidence of copper mineralisation in the ore-deposits of Area A is sparse. The soils consequently show relatively low values for this metal, ranging from 45 to 475 ppm. The level in the plant samples ranges from 22.5 to 300 (1.53 to 13.20) ppm, with the higher values generally occurring in the leaves or stems.

The majority of the species sampled are associated with the ore-deposits, or have been observed in the vicinity of mineralisation in other areas. The low sedge, Fimbristylis schultzii is restricted to the mineralised superficial crusts of Areas A and B. The sample analysed, (No. 41/48), is high in lead and zinc in keeping with the high concentrations in the underlying soil. The level of copper in the plant is low, though the soil is comparatively rich in this metal. On an oven-dry weight basis, the maximum value for copper occurs in the flowers, while the higher concentrations of lead and zinc are found in the leaves.

The second sedge sampled, Bulbostylis barbata, was also found in the Dugald River Area. In contrast to its occurrence in this region, however, the plant shows no direct affinity with the mineralisation in the Bulman region. The sample analysed from Area A lay in the path of drainage from a spoil heap of mineralised rock. The soil is therefore relatively high in lead and zinc and the plant, particularly the stems, is enriched in these metals. The concentration of copper, lead and zinc in the flowers is considerably lower than that in the stems; this again contrasts with specimens sampled from the Dugald River Area, where the flowers generally showed the highest degree of metal enrichment.

Three samples of different species were collected from the assemblage developed over the superficial mineralised crust at the 00 point of the transect, (Fig. 46). Polycarpaea synandra var. gracilis (Sample 41/49) shows a very close correlation with the surface outcrops of the ore-deposits. The concentration of zinc and lead, particularly the latter, is very much higher in the stems than in the flowers of this sample, while the stems also show a slightly higher degree of copper enrichment. The level of lead and zinc in the stems of P. synandra var. gracilis is considerably higher than in the samples of Aristida browniana and Tephrosia aff. polyzyga from this locality.

The sample of Euphorbia sp., (Bulman No. 172), was collected from an area underlain by dolomite, where, however, the soils were relatively high in lead and zinc. Both the leaves and stems of the sample contain appreciable quantities of zinc, but only the stems show a marked enrichment in lead. The level of this element in the leaves is the lowest of any sample, including flowers leaves and stems, from Area A.

Comphrena canescens occurs frequently, though not exclusively, on the mineralised superficial crusts of Areas A and B. The sample analysed contains 13.5% zinc in the ash of the leaves, (1.35% on an oven-dry weight basis), compared with a soil concentration of 8.5% zinc. Both values are the maximum recorded in plant material or soils from this region. The concentration of this element, and also lead, in the leaves, is appreciably greater than their concentrations in the flowers or stems of this sample. The leaves also show a slightly higher degree of copper enrichment than the other aerial parts of the plant.

The low herb, Galactia muelleri, is widespread over Areas A and B, but shows no distinct association with mineralisation. The sample analysed was collected from sub-outcropping chert near the western end of the transect, where the soils are low in lead and zinc compared with those elsewhere on the upland region. The plant, particularly the leaves, contains appreciable quantities of these metals, however. Copper is low in both the plant and the underlying soil, but again the maximum value in the plant, on an oven-dry weight basis, occurs in the leaves.

(3). Plant analyses from the Weimool Springs Grid

Six samples of herbaceous species and one sample of the low shrub, Tephrosia aff. polyzyga, were collected in this area. Notwithstanding the low levels of copper, lead and zinc in the soils of the region, some of the plant samples contain relatively high concentrations of these elements, (Table 31).

The results for copper, (including all aerial parts), range from 22.5 to 225 (1,60 to 8.50) ppm compared with a range of from 5 to 37.5 ppm in the underlying soils. The values in the plant samples are of the same order as those obtained from the samples from Area A where, however, the soils are appreciably higher in this metal. No definite pattern in the distribution of copper within the aerial parts of the plants is evident, high values occurring in the flowers, leaves and stems.

Several of the plant samples, particularly the stems, contain appreciable quantities of lead. The concentration in the plants ranges from < 5 to 550 (< 1 to 22.37) ppm over a range in soil lead content of 15 to 105 ppm. The maximum values in the aerial parts of the plants generally occur in the stems.

The soils of the area are also poor in zinc. The concentration in the near-surface soils underlying the plant samples shows a range of 25 to 150 ppm. Again, however, several of the plants sampled contain appreciable amounts of this element, with the higher values generally being found in the flowers or the leaves. The level in

Table 31 : Miscellaneous Species. Analyses of Plant Samples from Weimool Springs Grid, Bulman. Un-milled, dry-ashed material.

No.	Species	Locality	Part of Plant	% Ash	ppm of ash Cu	ppm of ash Pb	ppm of ash Zn	Cu/Zn Ratio	ppm of oven-dry material Cu	ppm of oven-dry material Pb	ppm of oven-dry material Zn	ppm of soil (6-8 ins) Cu	ppm of soil (6-8 ins) Pb	ppm of soil (6-8 ins) Zn	Cu/Zn Ratio	Soil Type
41/66	Tephrosia aff polygyga	Area South of drainage channel	Stems	3.09	50	15	800	0.062	1.54	0.46	24.72	Ranges in metal content in samples from this area. 15-35	20-100	50-130		Chert
41/47	Polycarpaea corymbosa	$100^{S}/50^{W}$	Flowers	6.59	87	55	750	0.12	5.76	3.62	49.42					Alluvium of drainage channel
			Leaves	10.01	85	30	300	0.28	8.50	3.00	30.03	35	105	70	0.50	
			Stems	3.44	87	< 5	950	0.092	3.01	< 1	32.68					
41/46	Gomphrena canescens	$40^{N}/40^{E}$	Flowers	7.21	60	60	520	0.11	4.32	4.32	37.50					Laterite and chert gravel on chert.
			Leaves	11.11	22.5	< 10	290	0.077	2.50	< 1	32.21	37.5	60	25	1.50	
			Stems	5.66	35	70	250	0.14	2.00	4.00	14.15					
41/65	Trianthema rhynchocalyptra	$120^{N}/25^{W}$	Flowers	12.14	35	35	130	0.27	4.25	4.25	15.78					Laterite gravel on chert
			Leaves	14.37	30	20	180	0.17	4.31	2.87	25.86	25	50	25	1.00	
			Stems	12.43	65	180	220	0.29	8.08	22.37	27.34					
41/43	Polycarpaea spirostylis	$200^{N}/50^{W}$	Flowers	2.81	130	20	440	0.29	3.65	0.56	12.36					Laterite and chert gravel on chert
			Leaves	6.40	25	< 5	500	0.050	1.60	< 1	32.00	15	25	40	0.37	
			Stems	1.77	175	375	600	0.29	3.09	6.64	10.62					
41/44	Polycarpaea spirostylis	$230^{N}/15^{W}$	Flowers	3.57	75	35	680	0.11	2.67	1.24	24.27					Laterite gravel on chert
			Leaves	5.43	60	< 20	1160	0.052	3.25	< 1.08	63.00	5	15	60	0.083	
			Stems	1.87	225	550	600	0.37	4.20	10.28	11.22					
41/45	Unidentified grass (No.123)	$230^{N}/15^{W}$	Stems	5.48	50	< 10	540	0.092	2.74	< 1	28.59	5	15	60	0.083	Laterite gravel on chert

the plants ranges from 130 to 1160 (10.62 to 63.00) ppm..

The majority of the species collected in this area have been observed in the vicinity of mineralisation, either in the Bulman Region or in other parts of Northern Australia. The small shrub, Tephrosia aff. polyzyga, occurs on the mineralised superficial crusts of Areas A and B, but also has a scattered distribution in the Weimool Springs Grid Area. Owing to its small size, the analysed sample was a composite one, comprising material from a number of different specimens growing south of the drainage channel, (Fig. 47B). As in the sample from Area A, most of the leaves had been shed at the time of collection, and only the stems were available for analysis. These contain a relatively high concentration of zinc, though the levels of copper and lead are low.

Polycarpaea corymbosa is fairly common on the alluvium of the drainage channel which traverses the Grid. This material contains higher amounts of copper, lead and zinc than the soils of other parts of the area, (Fig. 48), but only zinc shows an appreciable enrichment in the plant. The maximum value for this metal occurs in the flowers, while lead and copper show the highest degree of enrichment in the flowers and leaves respectively.

The sample of Gomphrena canescens, was collected from the zone of lateritic gravel north of the drainage channel, where the herb is fairly common. In contrast to the sample collected from the mineralised superficial crust of Area A, (Table 30), where the maximum concentrations of copper, lead and zinc were found in the leaves, this sample shows the highest degree of metal enrichment in the flowers. The plant contains relatively low amounts of copper and lead, but an appreciable quantity of zinc.

The distribution of the low herb, Triantema rhynchocalyptra, shows a close correlation with the areas north of the drainage channel where the surface soil is largely composed of lateritic nodules. The sample analysed shows maximum metal enrichment in the stems. On an oven-dry weight basis this organ contains a higher level of lead than any other plant sampled in the Weimool Springs Grid Area. The enrichment in zinc is less striking but the result for copper is also comparatively high for this area.

Two samples of Polycarpaea spirostylis were collected from areas with a veneer of lateritic gravel. These soils are low in copper, lead and zinc, but the plant samples contain appreciable quantities of these metals, particularly the last. The highest enrichment in zinc occurs in the leaves, that for lead in the stems, while in one sample the maximum value for copper, (on an oven-dry weight basis), is found in the flowers, and in the stems of the second sample.

A sample of the unidentified grass, Bulman No. 123, was collected from the same locality as the second sample of P. spirostylis. Comparing the level of copper, lead and zinc in the two samples, it is apparent that the flowers and stems of P. spirostylis are appreciably higher in lead than the grass. Copper shows little variation between the two species, while the zinc content in the grass is of the same order as in the flowers of the herb, though half of that in the leaves.

(4). Plant analyses from areas remote from known mineralisation

Three samples of different herb species were analysed from regions which, on the available geological evidence, were devoid of mineralisation. Within this group of samples, copper ranges from 15 to 105 (2.00 to 5.64) ppm; lead from $<$ 10 to 125 ($<$ 0.67 to 4.22) ppm and zinc from 80 to 440 (7.49 to 18.87) ppm, (Table 32).

Two of the species sampled, Polycarpaea synandra var. gracilis and Gomphrena canescens, are common on the outcropping lead-zinc ore deposits of Areas A and B, while the third, Heliotropium fasciculatum, shows no direct association with the mineralisation in this region.

P. synandra var. gracilis was sampled from the black soil plain south west of Area A, (Fig. 41), where the herb covers quite an extensive area. This was the only occurrence observed in areas remote from known mineralisation. The plant shows no marked enrichment in copper

Table 32: <u>Miscellaneous Species</u>. Analyses of Plant Samples from Areas not known to be Mineralised, Bulman. Un-milled, dry-ashed material.

No.	Species	Locality	Part of Plant	% Ash	ppm of Ash			Cu/Zn Ratio	ppm of oven-dry material			ppm of soil (6-8 ins)			Cu/Zn Ratio	Soil Type
					Cu	Pb	Zn		Cu	Pb	Zn	Cu	Pb	Zn		
41/64	Polycarpaea synandra var.gracilis	Black soil plain 1 mile SW of Area A	Flowers	3.58	105	<10	320	0.33	3.75	<1	11.45	240	21	140	1.71	
			Leaves	5.95	80	<20	240	0.33	4.76	<1.19	14.28	25	15	40	0.62	Alluvium
			Stems	2.14	100	<10	350	0.28	2.14	<1	7.49	Both samples from vicinity of plant occurrence.				
41/62	Gomphrena canescens	3 miles NW of Weimool Springs Grid	Flowers	6.99	65	<10	270	0.24	4.54	<1	18.87					
			Leaves	13.98	15	10	120	0.12	2.00	1.34	16.05	10	<10	30	0.33	Laterite gravel on chert
			Stems	4.51	60	<15	210	0.28	2.70	<0.67	9.47					
41/40	Heliotropium fasciculatum	13 miles NW of Weimool Springs Grid	Flowers	20.51	27.5	<10	80	0.34	5.64	<2.05	16.40					Chert
			Stems	3.38	75	125	440	0.17	2.53	4.22	14.87					

or zinc, while lead is at the lower limit of detection in the flowers, leaves and stems. Analyses of two soil samples from the vicinity of the plant gave rather conflicting results. One sample contained relatively high concentrations of copper and zinc, while the second was low in both metals. The tenor of lead was low in both samples.

The remaining samples were collected from the region north-west of the Weimool Springs Grid, and near the line of the Bulman Fault. Gomphrena canescens, while common on the superficial crusts at Areas A and B, also has a scattered distribution in areas occupied by lateritic gravel. Sample 41/62 contains relatively low concentrations of copper, lead and zinc, while the underlying soil is also poor in these elements. The sample of Heliotropium fasciculatum was collected from an area of outcropping chert still farther to the north-west of the Bulman Prospect. Here again the plant shows low enrichment in copper and zinc, though the stems contain an appreciable quantity of lead.

(5). Discussion

Although insufficient samples have been collected for a proper estimation of the normal or "background" levels of copper, lead and zinc in the herbaceous plants of the Bulman Area, it would appear that the overall concentrations of the first two metals, and possibly also of lead, are higher than those at the Dugald River. The mean background values for copper, lead and zinc in the latter area were 44 (2.42) ppm, $<$10 ($<$1) ppm and 119.3 (6.52) ppm respectively, (Table 8). Comparison of these values with the results of plant analyses from areas not known to be mineralised in the Bulman region, (Table 32), indicates that the level of copper and zinc in the latter group of samples is generally higher. Although Polycarpaea synandra var. gracilis and Gomphrena canescens are found in the vicinity of the ore-deposits in the Bulman Area and may, therefore, like Polycarpaea glabra in the Dugald River Area, show a tendency to metal accumulation even in barren areas, the level in these two samples is not appreciably higher than in the sample of Heliotropium fasciculatum. This species shows no direct association with mineralisation in the Bulman Area.

As in the Dugald River Area, the distribution of copper, lead and zinc within the aerial parts of the plants varies widely. At the higher concentrations of soil lead and zinc, the maximum values within the plants were found either in the leaves or the stems. (Since the different organs varied in ash content, this discussion is based on the metal content in the oven-dry material). When growing in soils containing small quantities of these metals, however, some species showed the greatest degree of enrichment in the flowers.

From the evidence provided by Bulbostylis barbata, it would appear that differences in the distribution of metal within the aerial parts of one species may occur from one region to another. In the sample analysed from Area A the metal maxima occurred in the stems, while in the samples from the Dugald River Area the higher metal contents were almost invariably found in the flowers, (Table 20).

The results also indicate that different species of the same genus may show variation in the distribution of metals within the aerial parts. Thus, in the sample of Polycarpaea corymbosa from the Weimool Springs Grid, the higher values for lead and zinc were found in the flowers and that for copper in the leaves. Samples of P. spirostylis from the same area, however, showed the maximum lead enrichment in the stems, that for zinc in the leaves, while the highest values for copper occurred either in the flowers or in the stems.

Comparison of the results of analyses of Gomphrena canescens from the Weimool Springs Grid with that from Area A also shows that the distribution of lead and zinc within the one species may vary according to the tenor of these metals in the soil. In the sample from the former area, the higher values for lead and zinc occurred in the flowers. In the Area A sample, however, the maximum concentrations of these elements were found in the leaves.

The distribution of copper also varies, though the level of this metal between the two areas shows a smaller difference than lead or zinc. In the Weimool Springs Grid sample the flowers show the highest degree of enrichment, while at Area A it is the leaves.

The reason for these variations in the distribution of metal, both between and within the plant species, is unclear. The explanation possibly lies in differences in the physiological processes involved in metal uptake within the plants, but extensive experimental work would be required before this could be confirmed. The variations do illustrate, however, the desirability, where possible, of sampling only one part of one species in biogeochemical prospecting within a region.

The majority of the plant samples collected in the Weimool Springs Grid Area showed a higher degree of enrichment in lead and zinc than the samples from other areas remote from known mineralisation within the Bulman region. Whether these high values are related to mineralisation is at present unknown. Most of the plants were collected from the zone of lateritic gravel, where the geochemical results indicate low concentrations of lead and zinc. Although the alluvium of the drainage channel traversing the Grid contains slightly higher levels of these metals, (Fig. 48), the sample of <u>Polycarpaea corymbosa</u> from this locality showed no appreciable increase in the concentration of lead and zinc over the plants from the zone of lateritic gravel, (Table 31).

Comparison of the copper:zinc ratios within the two groups of samples indicates that, generally speaking, the copper:zinc ratios in the Weimool Springs Grid samples are lower than those from plants growing in other areas remote from known mineralisation. The mean copper:zinc ratio in the samples, (all aerial parts) from the former area is 0.168 and the range 0.050 to 0.37, compared with a mean of 0.26 and range of 0.12 to 0.34 in the samples from areas remote from known mineralisation. Further sampling of plants from un-mineralised localities in the Bulman region would be required before this difference could be termed significant, but it is interesting to note that about one-third of the Weimool Springs Grid samples gave copper:zinc ratios below the value of 0.1. In the Dugald River Area ratios below this value were considered as probably indicative of zinc mineralisation in the underlying rocks.

Until further studies, both geochemical and biogeochemical, have been carried out in the Bulman region, the significance of the enrichment in lead and zinc shown by the plants of the Weimool Springs Grid Area, and the low copper:zinc ratios, cannot be fully elucidated.

The results from Area A indicate that the plants growing over the mineralised superficial crusts of this area can absorb extremely high concentrations of lead and zinc without apparent injury. Although the level of copper in the underlying soil is generally higher than in the Weimool Springs Grid Area, (ranging from 45 to 475 ppm as against 5 to 37.5 ppm), the plants show no decided increase in the concentration of the metal over the samples from the latter area. This tends to confirm the evidence obtained from several species in the Dugald River Area, i.e. that up to a concentration of at least 600 ppm in the soil, no appreciable variation in the level of copper in plants is likely to occur.

Comparison of the metal uptake by the species Polycarpaea synandra var. gracilis, Aristida browniana and Tephrosia aff. polyzyga, from the same locality, (on the mineralised superficial crust of Area A), indicates that the enrichment in lead and zinc shown by the three species decreases in the order named. This variation may be due to differences in the ability of the plants to absorb lead and zinc, but it may equally well be related to variations in the concentrations of lead and zinc in the underlying rock. Until a larger number of samples have been analysed, it is not possible to state conclusively that the three species show inherent differences in the uptake of metals.

It will be recalled that, in the Dugald River Area, it was suggested that the species associated with mineralisation had evolved separate ecotypes capable of withstanding high metal concentrations in the soil. This was taken as a possible explanation of the variations in the rate of metal uptake shown by the species at different concentrations of lead and copper in the soil. Intraspecific variation might also serve to explain the fact that all these species occurred both in the vicinity of mineralisation and in areas where the tenor of copper, lead and zinc in the soils was low.

More extensive sampling would be required to show whether the species associated with mineralisation in the Bulman region, i.e. Polycarpaea synandra var. gracilis, Gomphrena canescens, Tephrosia aff. polyzyga, Aristida browniana and Fimbristylis schultzii, show variations in the rate of metal uptake of this kind. However, with the exception of the last-named, all these species were observed in regions where the soils were low in the analysed elements. In view of the abrupt change in the vegetation over the ore-deposits, it is apparent that the presence of excessive quantities of lead and zinc in the rooting medium has a marked effect on plant distribution. Since most plant species are restricted to relatively narrow range of habitats, it might be expected that the species occurring on the ore-deposits would be restricted to these areas. Since this is evidently not the case, then intraspecific variation may serve as a possible explanation of their distribution patterns. It is suggested that the species occurring on the ore-deposits have evolved separate ecotypes, better adapted to the conditions obtaining in these areas than the species populations found in areas where the soils are low in the ore-metals.

It is also possible that the variations in the mode of occurrence, and in the distribution of metal within the plant, indicated by Bulbostylis barbata between the Bulman and the Dugald River Areas may be related to intraspecific variation within the species. It is suggested that the plant has evolved a separate ecotype in the Dugald River Area, capable of surviving under the toxic conditions of the ore-deposits, while in the Bulman region no such ecotype has been produced. The variation in the distribution of metal within the plant may therefore be related to the fact that two separate ecotypes were sampled.

As in the Dugald River Area, however, growth experiments under controlled conditions would be required before it could be conclusively stated that intraspecific variations of the type suggested have occurred in the plants associated with mineralisation in the Bulman region.

(6). Conclusions

(i). Samples of herbaceous plants from un-mineralised localities in the Bulman region generally contained amounts of zinc, copper and lead in decreasing order of abundance.

(ii). Although relatively few samples have been analysed, it would seem that the background levels of copper and zinc, and possibly also of lead, in the herbaceous plants growing in this region are higher than those of the Dugald River Area.

(iii). The plants growing over lead and zinc mineralisation contained considerably higher concentrations of these elements than similar plants growing in areas remote from mineralisation.

(iv). The plants sampled from Areas A and B, where the soils are comparatively rich in copper, showed little increase in the uptake of this metal over plants from the Weimool Springs Grid, where the soils are low in this metal. This confirms the findings in the Dugald River Area, i.e. that little increase in the concentration of copper in herbaceous plants takes place up to a soil copper content of at least 600 ppm.

(v). Wide variations in the distribution of metals within the aerial parts of the plants occurred, both from species to species and according to the metal in question. On the evidence of the herb, Gomphrena canescens, it appears that the distribution of metal within one species may vary according to the metal concentrations in the underlying soil. At low soil metal contents, the maximum values for copper, lead and zinc in the aerial parts of this plant were found in the flowers. At the higher levels of soil lead and zinc content, however, the maximum values occurred in the leaves.

(vi). Analyses of samples of Bulbostylis barbata from both the Bulman and Dugald River Areas indicates that variations in the distribution of metal within the aerial parts of one species may occur between different regions. In the Dugald River Area this species, frequently, though not exclusively, associated with mineralisation, showed the highest degree of metal enrichment in the flowers. In the Bulman Area however, where the plant does not occur on the ore-deposits, the highest values in the plant were found in the stems. These variations in the distribution pattern, and in the distribution of metal within the aerial parts of the plant, may be related to intraspecific variation within Bulbostylis barbata.

(vii). Samples of herbaceous plants from the Weimool Springs Grid Area generally contained higher quantities of lead and zinc than plants from other areas not known to be mineralised. Moreover, the mean copper:zinc ratio in the samples from the Weimool Springs Grid was considerably lower than that from the latter group of samples. These variations may be due to the presence of mineralisation in the rocks below the Weimool Springs Grid Area, though, apart from the alluvial soils of the drainage channel which traverses the area, the soils are generally low in these metals.

(viii). Samples of Polycarpaea synandra var. gracilis and Gomphrena canescens, species which occur on the lead-zinc ore-deposits of the region, did not contain abnormal quantities of copper, lead or zinc when growing in areas remote from known mineralisation. Analysis of the near-surface soil in the vicinity of the P. synandra var. gracilis occurrence gave conflicting results, one sample containing appreciable quantities of copper and zinc and the second containing small amounts of these metals. Lead was low in both samples. The soil of the G. canescens occurrence was poor in all three metals. Further investigations, particularly of the P. synandra var. gracilis occurrence, (since this species shows the closest correlation with the mineralisation at Areas A and B), would be required before it can be stated that the occurrence of these plants in areas remote from known mineralisation is indicative of ore-deposits at depth.

(ix). It is possible that edaphic ecotypes, of the type postulated for the species associated with mineralisation in the Dugald River Area, have also been evolved by the species occurring on the ore-deposits in the Bulman region. With the exception of Fimbristylis schultzii, all these species may be found in areas where mineralisation has not been proved and where the soils contain low concentrations of ore-metal. Although more extensive sampling, and preferably growth experiments, would be required to confirm this, intraspecific variation would seem to offer a reasonable explanation of the distribution patterns of these plants. It is suggested that these species have evolved separate ecotypes, capable of withstanding higher concentrations of lead and zinc in the rooting medium than the strains growing in barren areas. Their adaptation to these conditions may lie in their better ability to absorb large quantities of lead and zinc than the strains, or other more widespread species, which occur in un-mineralised regions.

SECTION K: SUMMARY OF CONCLUSIONS REGARDING VEGETATION DISTRIBUTION IN THE BULMAN AREA

(1). Summary of conclusions on the distribution of the major vegetation units

(i). Large tracts of upland country in the Bulman Area are occupied by a tall to mid-height Savanna Woodland sub-formation. This comprises a fairly open tree canopy, a shrub layer which is absent or poorly-represented, and a dense herbaceous vegetation dominated by tall perennial grasses. As the elevation decreases, this unit gives way, first to a more open association intermediate between Savanna Parkland and Grassland, and then, on the poorly-drained alluvial plains, to an extensive Savanna Grassland. Small areas of calcareous soils on the plains support a Thicket sub-formation.

(ii). Separate communites or associations within the Savanna Woodland sub-formation are characteristic of the three main types of upland topography. These comprise massive cherts, (interpreted as pallid zone material of a former lateritic profile, and in places veneered by lateritic gravel), dolerite sills and the carbonate rocks of the Bulman Formation. The last two rock types give rise to shallow gravelly soils.

Although many species, particularly Erythrophleum chlorostachys, Gardenia megasperma, Vetiveria elongata, Chrysopogon pallidus and Andropogoneae indet., (Bulman

No. 156), carry over from one of these environments to the next, the association occurring on the cherts is distinctive, both in floristic composition and by the taller stature of the tree species, from those occurring on the other habitats. These show a closer similarity.

(iii). The deep alluvial soils which occupy regions of low elevation in the Bulman Area may be subdivided into heavy dark-grey clay soils, fine-textured calcareous soils, and calcareous soils with gilgai development and calcrete nodules. Pure Savanna ~~Woodland~~ Grassland, dominated by *Sorghum* sp., (Bulman No. 184), *Chionachne cyathopoda* and *Iseilema vaginiflorum*, is restricted to the dark grey clays and to part of the area occupied by the calcareous soils with gilgais. The remainder of the latter area supports a dense Thicket of *Pipturus argenteus*. The fine-textured calcareous soil without gilgai micro-relief carries a Savanna Grassland studded by the palm, *Pandanus* sp.

(iv). The distribution of the major vegetation units within the Bulman Area is largely governed by drainage and edaphic factors, which in turn are influenced by the relief. The edaphic factor is of particular importance, since this affects not only the pH of the soil, but the water-holding capacity. Both have an important effect on vegetation distribution within the region. Although the nature of the bedrock geology largely determines the character of the Skeletal Soils, this is masked by alluvium or deep soils over a large part of the region. Hence, in these areas, the geology is of minor importance as regards the distribution of the associations and communities.

(2). <u>Summary of conclusions on the distribution of plant species associated with mineralisation</u>

(i). Zones of outcropping lead-zinc mineralisation in the limestone and dolomite rocks of the Bulman Area are occupied by an assemblage of <u>Polycarpaea synandra</u> var. <u>gracilis</u>, <u>Gomphrena canescens</u>, <u>Aristida browniana</u>, <u>Tephrosia</u> aff. <u>polyzyga</u> and <u>Fimbristylis schultzii</u>.

(ii). With the exception of <u>Fimbristylis schultzii</u>, all the assemblage species may be found in regions where mineralisation is unknown, and where the soils are relatively low in the ore-metals. In these regions, however, the species are generally found as sub-dominants of the "normal" vegetation, and have not been observed growing together as distinct assemblages as over the ore-deposits. Of the remaining species, the distribution of <u>Polycarpaea synandra</u> var. <u>gracilis</u> shows the closest correlation with the zones of lead-zinc mineralisation.

(iii). The mineralised zones differ little in relief, drainage or soil depth and texture from neighbouring areas underlain by barren rocks. It would seem, therefore, that the marked variation in the vegetation over the ore-deposits is related to some chemical property of the soils. Although this has not been fully investigated at Bulman, the work in the Dugald River Area suggests that phosphorus may be enriched in the soils overlying mineralisation. The main factor governing vegetation distribution in these areas, however, is probably the high tenor of lead and zinc in the rooting medium.

(iv). Although experimental work is required to confirm this, it is possible that the plants associated with mineralisation have evolved separate ecotypes adapted to these conditions. It will be recalled that variations in the rate of metal uptake by the corresponding plants in the Dugald River Area was taken as possible evidence that intraspecific variation had occurred. Insufficient plant samples have been analysed to show whether metal uptake by the assemblage species in the Bulman Area also varies in this respect. Intraspecific variation may, however, explain the occurrence of the majority of these plants, both in mineralised regions, and in areas remote from known deposits and where the soils are comparatively low in the ore-metals.

(v). The plants occurring over the lead-zinc deposits are apparently well-adapted to very high concentrations of lead and zinc in the rooting medium. No indication of chlorosis or other symptoms of metal toxicity were observed. Analysis of plant samples from these areas indicates that they are extremely enriched in the ore-metals compared with the tenor of these metals in plants from un-mineralised regions. Although further sampling is required before a definite conclusion can be drawn, it is possible that the assemblage species, like their counterparts at the Dugald River, contain higher concentrations of the ore-metals than more widespread species when growing in the vicinity of the ore-deposits. This suggests that the species, or ecotypes, associated with mineralisation, can withstand higher quantities of the ore-metals in their tissues than members of the more widespread vegetation. This may serve as an adaptive mechanism which allows these species, or strains, to survive the high metal concentrations in the mineralised areas, while other plants therefore avoid these zones.

(vi). A sample of Polycarpaea synandra var. gracilis, growing on alluvial soils remote from known mineralisation, did not contain anomalous concentrations of the ore-metals. Analysis of the near-surface soils at this locality gave conflicting results, one sample being relatively high in copper and zinc while the second was low in both metals. Further investigation is required before it can be shown whether the plant, which otherwise is restricted to the outcropping lead-zinc deposits, is indicative of mineralisation in the underlying bedrock at this locality.

(vii). Polycarpaea spirostylis, Tephrosia aff. polyzyga, Gomphrena canescens and Trianthema rhynchocalyptra have been observed in the vicinity of mineralisation, either at Bulman or elsewhere in northern Australia. The occurrence of these species in the Weimool Springs Grid Area, however, is not associated with metal enrichment in the underlying near-surface soils. In view of the comparatively high concentrations of lead and zinc in plant samples, and in alluvial material, from this area, it is possible that mineralisation is present either in the vicinity, or at some depth below the present-day ground surface. Secondary dispersion of lead and zinc from an ore-body in the bedrock below might be inhibited by the thick deposit of chert which underlies the region. This may lend an added significance to the comparatively high tenor of these metals in the plant material and stream alluvium, but further investigations are needed.

(3). Summary of conclusions regarding plant prospecting methods

(a). Indicator plant prospecting

(i). With the exception of the low sedge, Fimbristylis schultzii, no species has emerged as a sure indicator of base-metal deposits in the Bulman Area. Apart from this plant, all of the species occurring over the lead-zinc mineralisation at Areas A and B have also been observed growing in regions which, on the available geological evidence, were devoid of mineralisation and where the soils showed little enrichment in the ore-metals.

(ii). In view of its inconspicuous appearance, F. schultzii, would appear to have little value as an indicator plant in reconnaissance prospecting for lead and zinc in this region. Of the remaining species associated with mineralisation, Polycarpaea synandra var. gracilis shows the closest link with the ore-deposits, but this species is also rather difficult to distinquish from a distance. It has small white inflorescences, short erect stems which wither to a brownish colour during the dry season, and small leaves. Gomphrena canescens, with its large reddish globe-shaped flowers, has a more striking appearance, but this species is relatively common in un-mineralised regions. Likewise, the low shrub, Tephrosia aff. polyzyga, and the annual grass, Aristida browniana, are comparatively frequent both in mineralised and barren areas.

(iii). Although the majority of the species associated with mineralisation have also been found in barren regions, they have not been observed growing together in distinct assemblages in the latter areas. While, therefore, individual occurrences of the species in areas remote from known mineralisation cannot be construed as indicative of an ore-deposit at depth, the present evidence indicates that the occurrence of the species as a distinct assemblage is probably related to underlying mineralisation.

(iv). Polycarpaea spirostylis has been used as an indicator plant for copper in eastern Queensland, but the distribution of this species in the Bulman region shows no obvious link with mineralisation. Likewise, Bulbostylis barbata shows a certain affinity with base-metal deposits in the Dugald River Area, but is not associated with the mineralised zones at Bulman. Thus a species which may be utilised as an indicator plant in one region, may not be assumed to show the same characteristic when found in another,distant area.

(v). Although the present investigation was in the nature of a reconnaissance survey, and further work in the region might give more encouraging results, it would seem that the indicator plant prospecting method shows less promise in the region compared with the Dugald River Area. In part this is related to the more luxuriant ground vegetation in the Bulman Area, the taller grasses forming a denser cover than at the Dugald River. Moreover, the species associated with mineralisation at Bulman have, generally speaking, a much less distinctive appearance than the corresponding plants in the Dugald River Area. These combined factors make reconnaissance prospecting for base-metals by indicator plants a much more difficult task than in the latter area.

However, as in the Dugald River Area, the distribution of plant assemblages over known ore-deposits, as at Areas

A and B, might form a useful guide in the initial determination of the surface extent of the mineralised rocks.

(b). Biogeochemical prospecting

(i). Plant sampling for biogeochemical analysis in the Bulman Area was on a more limited scale than at the Dugald River, and hence fewer definite conclusions can be drawn. It is manifest, however, that large amounts of lead and zinc in the rooting medium in the vicinity of the ore-deposits are reflected by anomalous concentrations of the ore-metals in the herbaceous vegetation over these zones.

(ii). Although insufficient samples from un-mineralised localities have been analysed to give an accurate estimation of the background levels of copper, lead and zinc in plants, it would seem that these values are higher than in the Dugald River Area. This illustrates the desirability of collecting separate background samples for each region where biogeochemical investigations are to be carried out.

(iii). Comparison of the concentrations of ore-metal in the flowers, leaves and stems of the plants sampled indicates that widespread variations occur. These take place both between and within different species, and according to the concentration, and identity, of the ore-metal in the underlying soil. Moreover, comparison of metal uptake between Bulbostylis barbata samples from the Bulman and Dugald River Areas shows that variations may take place within one species from different regions. Where possible therefore, biogeochemical sampling within one area should be confined to one part of one species.

(iv). Although several of the plants collected in the Weimool Springs Grid Area showed a relatively high degree of enrichment in lead and zinc, it is not known whether this is related to mineralisation at depth. It is possible that it reflects the generally higher tenor of lead and zinc in the background vegetation of the Bulman region, compared with that in the Dugald River Area, (ii).

(v). Although biogeochemical analysis in the Bulman Area has shown that anomalous concentrations of lead and zinc in the soil are reflected in plants, it should be noted that these samples were collected from an area of outcropping mineralisation.

The deep chert horizon which masks much of the bedrock in the region poses a difficult problem in mineral exploration. This will probably tend to inhibit the secondary dispersion of metal from an ore-deposit into the overlying surface soil layers. If this be the case, then prospecting by geochemical methods in these regions would seem to offer little chance of success. On the other hand, if it can be shown that the high metal contents in some of the samples from the Weimool Springs Grid reflect the presence of mineralisation at depth, then plant analyses would appear to offer a valuable aid to base-metal prospecting. Until these anomalous values have been investigated, however, it is difficult to draw any firm conclusions on the value of the biogeochemical method in the region.

(vi). In view of the presence of the chert horizon over large parts of the Bulman region, it is possible that analysis of the deeper-rooted tree species might form a better guide to underlying mineralisation than the herbaceous or shrub vegetation. Whether tree roots penetrate the chert deposit is not known, but it seems probable that they reach greater depths than the roots of the lesser plants. Hence the presence of an ore-deposit in the bedrock might be reflected by anomalous ore-metal contents in the trees, while the herbaceous and shrub plants show no variation.

SECTION L: GENERAL CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

(1). The distribution of the major vegetation units

(i). The vegetation of both the Dugald River and Bulman Areas is adapted to a long dry season, most prolonged in the former area. At the Dugald River the average annual rainfall is about 17 ins., while in the Bulman region, due to the increased influence of the north-west monsoon, the annual rainfall is probably of the order of 35 ins.

This variation has an influence on the stature of the dominants of the tree and herbaceous strata in the respective areas. At the Dugald River the most widespread sub-formation is a Low Tree and Shrub Savanna, comprising a fairly open cover of low trees and shrubs and a relatively sparse ground vegetation in which the dominant grasses rarely exceed a height of two feet. In the Bulman Area this sub-formation is replaced by a Savanna Woodland of tall, slender, trees, with a dense ground stratum dominated by tall perennial grasses. Savanna Grassland occupies poorly-drained clay soils in both regions, but again the dominant grasses are considerably taller in the Bulman Area.

(ii). Adaptation to the seasonal distribution of the rainfall primarily takes the form of mechanisms to reduce transpiration during the dry season. Sclerophyllous leaves are common among the trees and shrubs, while, particularly in the Bulman region, dry-season deciduous specie are also frequent. The majority of the perennial grasses die back during the rainless period, growth being resumed from vegetative buds at the onset of the following wet sea son. However, the coarse, xeromorphic, grass, Triodia pungens, widespread in the Dugald River Area, remains relatively green throughout the year.

(iii). The rigorous nature of the climate has a marked affect, not only on the physiognomy of the vegetation, but, through these factors which govern the availability of water, on plant distribution. Drainage and soil depth and texture, therefore, appear to have the most direct bearing on the distribution of the major vegetation units within the Dugald River and Bulman Areas. These factors are in turn affected by the relief, the geomorphological processes which have shaped, or are shaping the landscape, and on the nature and extent of the soil parent material.

(iv). The soil reaction is also important, however. In both regions there is a marked variation in floristic composition, and in certain cases in structure, between the vegetation occupying acid soils and that on basic material.

(v). Although variations occurred in the major and trace element content of soils occupied by different vegetation units in the Dugald River Area, these variations were not pronounced. Moreover, the level of the elements analysed within a zone occupied by a single vegetation unit also showed wide fluctuations. It seems probable, therefore, that these factors enumerated under (iii) and (iv) above have a more direct bearing on the distribution of the associations and communities within the study-areas.

(2). The distribution of the species associated with mineralisation

(i). Outcropping lead-zinc and copper deposits in the Dugald River Area, and deposits of lead-zinc ore at Bulman, support distinctive assemblages comprising several herb, grass, sedge and shrub species. On the other hand, the more widespread plants generally avoid these zones. No symptoms of metal toxicity were observed in the assemblage species, and they are therefore apparently well-adapted to survival on the metal-rich soils overlying the mineralised zones.

(ii). There is no essential difference in the specific composition of the assemblages occurring on lead-zinc deposits and those on copper mineralisation in the Dugald River Area. However, the assemblage species are rarely found in the vicinity of copper showings in calcareous host rocks. As evidenced by their distribution where both acid and basic soils occur, this is probably related to the fact that the plants are intolerant of the latter type of environment.

(iii). Factors of relief, drainage, soil depth and texture, and the pH status of the soil appear to have little influence on plant distribution in the immediate vicinity of the mineralised zones. Certain elements besides the ore-metals, notably phosphorus, show an enrichment in the soils overlying the ore-deposits at the Dugald River. It is probable, however, that excessive concentrations of copper, lead and zinc, and possibly also of silver, in the rooting medium, is the prime factor governing the extent of the assemblages developed over the ore-deposits.

(iv). While no metal has emerged as having a dominant influence on plant distribution over the ore-deposits, it is possible that zinc is of least importance. Thus the more widespread plants can apparently withstand higher concentrations of zinc in the rooting medium than the other ore-metals. Moreover, analysis indicates that zinc shows the most decided enrichment within plant material compared with the level in the underlying soil.

(v). The majority of the species associated with mineralisation in both study-areas may also be found in areas apparently devoid of mineralisation. At several of the latter occurrences in the Dugald River Area, the plants marked the sites of zones of minor copper and/or zinc enrichment in the underlying soils. The evidence is less conclusive at Bulman. This enrichment may be related to mineralisation at depth, but further investigation of these areas is required.

(vi). The concentration of copper, lead and zinc in the aerial parts of the assemblage species over deposits of these metals in the Dugald River Area was generally higher than in samples of more widespread plants from the same localities. This apparent ability to absorb large amounts of the ore-metals without injury may serve as an adaptive mechanism among the species associated with mineralisation.

(vii). Analyses of the aerial parts of several of the assemblage species from the Dugald River indicates that the rate of copper and lead uptake by the plants was not constant. Up to a certain level in the soil; the concentration of lead and copper in the plants increased slowly; above this point, the plant metal content showed a marked rise over a comparatively small increase in the soil metal content. In contrast, however, the zinc content in the plants increased linearly with the concentration of this metal in the underlying soil.

(viii). These variations in the rate of metal uptake by certain of the plants associated with mineralisation may be related to intraspecific variation. It is suggested that the populations occurring on the mineralised zones represent ecotypes, specifically adapted to these conditions, of the assemblage species. This adaptation probably takes the form of physiological ability to withstand large quantities of the ore-metals in the plant tissues. This may explain the distribution pattern of these plants. If only one population were involved, it might be expected, (in view of the marked influence high soil metal contents apparently have on plant distribution), that plants would be restricted, either to mineralised areas, or to barren regions, but would not occur in both.

It is recommended that the assemblage plants be grown under controlled conditions to determine whether such ecotypes do, in fact, exist. This would involve cultivation of populations from the vicinity of the ore-deposits, and populations from un-mineralised regions, in soils containing high concentrations of copper and/or lead. If it can be shown that, under these conditions, there is a marked difference in the growth of the two populations, then this would form fairly good evidence of intraspecific variation within the plants. A close study of specimens from the two types of occurrence might also reveal morphological differences. This was difficult in the present investigation due to the generally poor condition of the vegetation at the time the field work was carried out.

(ix). The fact that rising concentrations of zinc in the plants shows a roughly linear relationship with the level of this element in the underlying soil, may indicate that zinc is less toxic than copper or lead, (iv). If this be the case, then the more widespread plants may be equally well adapted to growth on zinc-rich soils as the assemblage plants.

However, in view of the nature of the ore-deposits, it is difficult, under field conditions, to find soils rich in zinc but with minor amounts of lead, and vice versa. It would be of interest, therefore, to grow collections of the assemblage and widespread plants on two different soils, one containing excess lead and the second with excess zinc. If both collections thrive on the zinc-rich soils, but only the assemblage plants on the soil with excess lead, then the latter metal would seem to have the more decided influence on plant distribution over the lead-zinc deposits.

(x). The sequence of events leading up to the establishment of the plant assemblages over the mineralised zones was possibly as follows. As the ore-deposits were exposed by erosional forces the overlying soils were enriched in the corresponding ore-metals. At first, due to the toxic metal contents, these zones may have been devoid of vegetation. Gradually, however, (possibly due to increased competition from other plants), the species comprising the present-day assemblages evolved ecotypes capable of surviving under these conditions.

The populations of the assemblage species now found in apparently un-mineralised areas may represent the original population from which the ecotypes were evolved. Alternatively, they may represent strains, initially adapted to growth on the metal-rich soils and restricted to these areas, which have now migrated into barren areas. At present there is insufficient evidence to indicate which of these hypotheses, if any, is the more likely explanation of the distribution pattern of the plants associated with mineralisation.

(xi). Different species of Tephrosia, Polycarpaea and Fimbristylis, are represented in the assemblages occurring over the mineralised zones in both the Dugald River and Bulman Areas. It is also of interest that Bulbostylis barbata, while present in both regions, only shows an association with mineralisation at the Dugald River. Similarly, Polycarpaea spirostylis has been reported as showing a close link with copper deposits in eastern Queensland, but was not found in the vicinity of the ore-deposits at Bulman though occurring in the region.

If the postulate of intraspecific variation is correct, then it is apparent that certain genera, or species, have an inherent tendency to evolve ecotypes adapted to survival on the metal-rich soils over ore-deposits. The distribution of B. barbata and P. spirostylis, however, suggests that such ecotypes have a fairly limited geographical range. These variations in the habitats favoured by the plants associated with mineralisation in different regions, would appear to make an interesting subject for further research.

(3). Plant prospecting methods

(a). Indicator plant prospecting

(i). The distribution of the species associated with mineralisation in the Dugald River and Bulman Areas suggests that they could be utilised, under certain conditions, as indicator plants in prospecting for base metals. Certain of the species associated with mineralisation in the Dugald River Area were also found in the vicinity of other ore-deposits in the Mt. Isa-Cloncurry mineral field. Likewise, several of their counterparts at Bulman have also been reported over mineralised zones in other parts of the Northern Territory.

(ii). The indicator plants of the Dugald River Area are apparently intolerant of basic soils. On the available evidence, therefore, it is unlikely that they will occur to any significant extent over mineralisation when set in calcareous host rocks.

(iii). Both lead-zinc and copper deposits are found in the Dugald River Area, but none of the indicator plants show a definite link with one and not the other type of mineralisation. Localities where the indicator plants occur, therefore, must be investigated to show which, if any, ore-metal is enriched in the substrate. Geochemical methods would be particularly useful in this respect, especially when the plants occur in regions of covered ground.

(iv). The indicator plants in both the study-areas have only been found individually in regions apparently barren of mineralisation, and never as distinct assemblages as over the ore-deposits. On the present evidence, therefore, the discovery of several of the indicator plants growing together is a sure sign of mineralisation in the underlying rocks.

(v). Some of the separate occurrences of the indicator plants outwith zones of known mineralisation may be related to minor zones of copper and/or zinc enrichment in the underlying soils. This was particularly true of the Dugald River Area. The distribution of the individual species in areas which are not known to be mineralised may thus serve to pinpoint the sites of soil metal anomalies, and thereby narrow the range of operations in geochemical prospecting.

(vi). In addition to their use in reconnaissance prospecting, the distribution of the indicator plants over known base-metal deposits may also serve as a guide in the initial determination of the surface extent of the ore-body.

(vii). The method of indicator plant prospecting would appear to have more application in the Dugald River Area than at Bulman. In the former area the indicator plants have a very distinctive appearance, while at Bulman they are, in general, relatively inconspicuous. Moreover, the normal ground vegetation in the Bulman region is considerably denser and taller than at the Dugald River. This again serves to render the plants much more easily visible from a distance in the latter region, and hence of more value in prospecting.

(viii). One of the species associated with mineralisation in the Dugald River Area did not show this characteristic when found at Bulman. Likewise, a species which has been used as an indicator plant for copper in eastern Queensland shows no obvious link with mineralisation in the Bulman Area.

While some of the indicator plants have a wide geographical range, therefore, the above evidence suggests that they need not show the same affinity with mineralisation throughout their area of occurrence. Thus, when field operations move from one region to another, an initial survey should be made of all known ore-deposits to indicate whether the indicator plants used in the previous area show the same association with mineralisation in the new region.

(b). Biogeochemical prospecting

(i). The herbaceous and shrub plants growing over the mineralised zones in the Dugald River and Bulman Areas contain considerably greater quantities of the ore-metals than similar plants growing in barren regions. This suggests that the systematic collection and analysis of plant samples could be used in prospecting for these metals.

(ii). The available evidence indicates, however, that significant variations in the metal content of plants are unlikely to take place unless the soils overlying a buried ore-deposit are considerably enriched in the ore-metals.

This is particularly true of lead and copper, since these metals show little increase in the plants up to a comparatively high concentration in the substrate. On the other hand, the level of zinc in the plants shows a roughly linear relationship with the zinc content in the underlying soil.

(iii). In agreement with their order of mobility in the soils of the Dugald River Area, the general order of enrichment in plant material decreases in the order zinc, copper, lead. The majority of the samples analysed from the zones of lead-zinc mineralisation in this area contained anomalous concentration of zinc. Likewise, anomalous concentrations of copper were generally found in plants growing over rocks rich in this metal. However, comparatively few plants from the former type of mineralisation were significantly enriched in lead.

This suggests that biogeochemical prospecting methods would have more application in the search for copper and zinc than for lead, though it should be remarked that zinc and lead generally occur together in the mineralised zones.

(iv). It appears that little advantage will be gained by using the ratio of copper to zinc in plants in prospecting for these metals, rather than their absolute values. As mentioned above, (iii), the majority of the samples from zones of copper and zinc mineralisation showed significant enrichment in the respective ore-metals.

(v). Variations in the distribution of ore-metal within the aerial parts of the plants sampled were common. These occurred both between and within the species analysed, according to the metal in question, and at different concentrations in the underlying soil. An initial investigation must therefore be made in any region, in order to ascertain which plant organ shows the most consistent relationship with the tenor of the ore-metals in the substrate.

(vi). Although relatively few samples were collected in the Bulman Area, there was a strong suggestion that the normal or "background" concentrations of copper and zinc, and possibly also of lead, were higher in the herbaceous and shrub vegetation of this region than in that of the Dugald River. This illustrates the desirability of separate determinations of the background levels within each area of operation.

(vii). In view of the variations in the distribution of metal within the aerial parts of plants, (v), biogeochemical sampling in any one area should, where possible, be confined to one aerial part of a single species. In regions of relatively shallow overburden, such as the greater part of the Mt. Isa-Cloncurry mineral field, the widespread grass, Triodia pungens, would seem to offer an effective sampling medium. When the depth of overburden is greater, as in the Bulman region, analysis of the deeper-rooted tree species might give a better guide to the tenor of the ore-metals in the bedrock than the herbaceous and shrub species.

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APPENDIX A

Techniques of soil analysis for major and trace elements

One or more samples weighing between 1 - 2 lbs., were collected from each horizon exposed in the soil profile pit or auger hole, and stored in numbered Kraft paper bags. These allow moisture to escape through the paper, but do not disintegrate.

The soil sample was poured on to glazed paper, mixed well, and quartered with a spatula. One quarter was passed through a 2 mm. mesh sieve, and the pH measured on the "fine earth".

A second quarter was crushed in a tungsten steel, (Pithocast), pestle and mortar to pass 60 mesh nylon bolting cloth in a perspex sieve.

The material was again quartered, and milled in a motorised agate pestle and mortar to pass 120 mesh nylon bolting cloth in a perspex sieve.

Care was taken throughout to avoid contamination. This material was used for major element and spectrographic analysis.

Analytical methods

(i). Hydrogen ion concentration: The pH was determined at the sticky point of the soil (minus 2 mm. fraction), on a glass electrode pH meter, (Jackson, 1958, p. 41).

(ii). Organic carbon: Walkley - Black method, with modification by Tinsley, (1950).

(iii). Total soil nitrogen: Modified Kjeldahl technique, in use at the School of Agriculture, University of Nottingham, where all analyses were carried out.

Description: About 2.5 gm accurately-weighed air-dry soil was transferred to a 250 ml. Kjeldahl flask. 20 ml. concentrated sulphuric acid was added, followed by about 1 gm. copper sulphate, and heat applied. On cessation of fuming, 9 gm. potassium sulphate and 1 gm. selenium in tablet form were added. Heat was continued for at least one full hour after the digest had assumed a pale green or straw colour.

After cooling, about 100 ml. distilled water was added, and the flask placed on the distillation apparatus. 10 ml. boric acid - mixed indicator solution, (see below), was added to the receiving flask. Finally, 80 ml. 40% sodium hydroxide and 1 gm. Devarda's alloy were added to the distilling flask; this was then connected to the apparatus, and heat applied.

Distillation was continued until 70 - 100 ml. had collected in the receiving flask, and no more ammonia, (as confirmed by litmus paper), was distilling off. The boric acid solution was then titrated against N/100 sulphuric acid. Blank digests were carried out, using o.2 gm. sucrose.

Boric acid-mixed indicator solution: Dissolve 20 gm. boric acid in 980 ml. distilled water, and add 20 ml. of mixed indicator, made by dissolving 0.099 gm. bromocreosol green and 0.066 gm. methyl red in 100 ml. ethyl alcohol (95%).

(iv). Hydrochloric acid extraction

Modified version of Hall's method, (Piper, 1950, p. 139).

Description: About 5 gm. accurately-weighed soil was placed in a 250 ml. Erlenmeyer flask, and 50 ml. concentrated hydrochloric acid added. The liquid was boiled for four hours in a fume cupboard, refluxing being obtained by cold finger condenser. 100 - 150 ml. of hot distilled water were added, and the contents filtered through a Whatman's No. 40 paper. Washing was continued with hot dilute hydrochloric acid, (50 ml. acid per litre), till the filtrate amounted to approximately 400 ml. This was then re-filtered to remove any traces of the soil, and made up to 500 ml. in a volumetric flask.

This solution was then used for the determination of phosphorus, potash and sodium.

(v). Phosphorus: Molybdophosphoric Blue Method, (modification of that described by Beadle and Tchan, 1955).

Description: An aliquot, (between 2 and 10 ml. according to the amount of phosphorus expected), was pipetted into a 50 ml. volumetric flask, and diluted with water. The solution was made slightly alkaline with IN-sodium hydroxide, using 2:4 dinitrophenol as indicator. Excess alkali was neutralised with O.IN-sulphuric acid. Water was added to make about 35 ml. 10 ml. of 0.25% ammonium molybdate and 0.5 ml. of freshly prepared stannous chloride solution were added, and the volume made up to 50 ml. The optical density was measured at 6750 Å on a Unicam Spectrophotometer, after a 30-minute interval.

(vi). Potash: EEl flame photometer, (Jackson, 1958, p.455)

(vii). Sodium: EEl flame photometer, (Jackson, 1958, p.455)

(viii). Summary of spectrographic method

The following information was kindly provided by Dr. D.V. Crawford of the School of Agriculture, University of Nottingham.

Sample preparation: The finely-ground soil sample (minus 120 mesh), was mixed with an equal weight of carbon powder, (ca. 7 mg.), in which was incorporated a palladium salt ($Pd\ Cl_2$) to give 0.10% Pd-metal in the carbon. This mixture was then shaken for two minutes in a vibratory mixer.

Spectrographic conditions

Spectrograph	Hilger Large Quartz (E 742/3)
Microphotometer ..	Hilger
Wavelength Range .	2800 - 5000 Å
Emulsion	Ilford (N.50)
Anode	Morganite carbon, flat-ended
Cathode	Morganite carbon, 0.8 mm. diam. centre . 8 mm. crater

Exposure Time ...	$2\frac{1}{2}$ minutes
Gap	10 mm.
Arc current	9 amps
Slit	0.01 mm.
Step Sector	7 steps giving intensities in ratio : 1,$\frac{1}{2}$,1/4,1/8,1/16,1/32, 1/64

Element lines used

Magnesium	3096
Iron	3021
Manganese	4031-4
Cobalt	3454
Copper	3247
Lead	2833
Molybdenum	3170

Measurement of line intensity

The line intensities of the unknown elements and the internal standard, (palladium), were measured on a Hilger microphotometer in conjunction with a Hilger Galvoscale Mirror galvanometer. Three readings were taken on appropriate line steps to bracket a galvanometer scale reading of 20.

Interpretation of results

The galvanometer readings were plotted against step number, using a plotting board with a set-square calibrated to give galvanometer deflections in terms of Siedel Densities. The log intensity ratio of the unknown: internal standard was then measured from the graph. The concentration of the unknown was obtained by comparing the log intensity ratio with calibration curves prepared under identical conditions.

APPENDIX B

Techniques of plant analysis for copper, lead and zinc

A. Collection, preparation and ashing

(1). Collection and storage

The plant samples were collected by hand except in the case of the harder species, e.g. Triodia pungens, where heavy gardening shears were required. Large samples were stored in clean polythene bags, and small ones in Kraft paper bags. The latter allowed drying to proceed normally, but with the polythene bags mould set in unless they were left unfastened for a few days. Temperatures were relatively high during the collection period, and air-drying removed most of the initial moisture.

(2). Contamination

Contamination by surface dust may give a positive bias to the results in samples from mineralised outcrops. Four plant samples were therefore cleaned by washing with a fine stream of de-ionised water, and a fifth with a fine brush.

The results from these samples are compared with those from duplicate, untreated, material in Table 33. It is apparent that considerable amounts of lead and zinc have been lost from the washed material of Sample 41/52, and smaller quantities from several of the other samples. The material cleaned by brushing, however, gave the same values as the untreated sample.

Table 33: Comparison of Results of Duplicate Analyses of washed or brushed Material with untreated Material. Plant Samples from Mineralised Outcrops. Un-milled, dry-ashed material.

No.	Species	Locality	Treatment	Part of Plant	% Ash	ppm of Ash Cu	ppm of Ash Pb	ppm of Ash Zn	Cu/Zn Ratio	ppm of oven-dry material Cu	ppm of oven-dry material Pb	ppm of oven-dry material Zn	ppm of soil (4-8 ins) Cu	ppm of soil (4-8 ins) Pb	ppm of soil (4-8 ins) Zn	Cu/Zn Ratio	Rock Type
41/49	Polycarpaea synandra var. gracilis	00 pt.- Bulman Area A	Washed	Stems	2.08	120	6400	72000	0.002	2.49	133	1497	200	3200	31000	0.006	Mineralised superficial crust
			Un-treated		2.95	100	8000	68000	0.002	2.95	236	2006					
41/52	Gomphrena canescens	125W on Transect-Bulman Area A	Washed	Flowers	6.63	35	350	23000	0.0015	2.32	23.2	1525	80	3400	85000	0.0009	Mineralised superficial crust
			Un-treated		6.83	30	480	32500	0.0009	2.05	32.8	2220					
			Washed	Leaves	10.37	25	960	120000	0.0002	2.58	99	12444					
			Un-treated		10.00	25	700	135000	0.0002	2.50	70	13500					
			Washed	Stems	2.83	40	500	32000	0.001	1.13	14.1	905					
			Un-treated		2.74	60	1200	55000	0.001	1.64	32.9	1507					
40/138	Polycarpaea glabra	1150S/ 365W Dugald R. Lode	Brushed	Young stems	2.31	525	<10	1600	0.33	12.13	<1	36.9	5700	35	480	11.87	Copper vein
			Un-treated		2.51	500	15	1600	0.31	12.55	0.4	40.2					

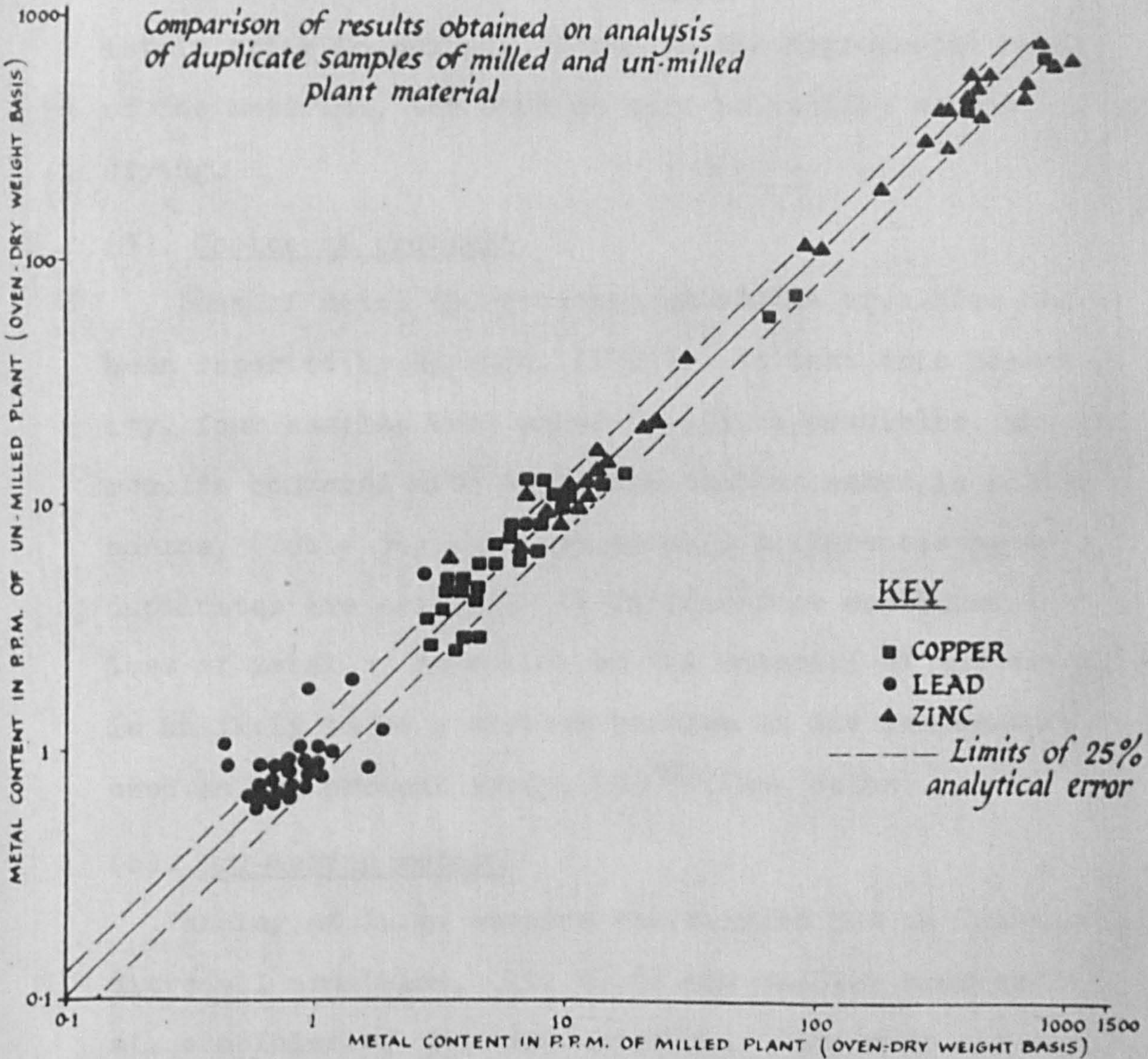
The water used in the washing of Sample 41/52 contained appreciable amounts of lead and zinc. This suggests that the metal removed from the plant was in a readily-soluble form, whereas if in the form of metal-rich dust it would have been relatively insoluble in water. In view of the close agreement between the brushed and untreated sample, therefore, it is probable that the bulk of the metal removed by washing was in a water-soluble form in the plant tissues and not as surface dust.

The writer would conclude that, provided sufficient care is taken to collect material above, say, two inches from ground level, contamination from metal-rich dust will no be a serious problem. On the other hand, negative error could occur by washing, due to the removal of water-soluble metal from within the plant tissues.

(3). Milling

In order to investigate whether milling the sample prior to the analyses would affect the results, 32 duplicate samples were milled in a Christy and Norris 5 inch Junior Lab Mill.

The metal contents in the milled samples have been plotted against the results from the untreated material in Fig. 49. It is evident that the great majority of the points fall within the limits of the 25% analytical error inherent in the analytical method, (see below). Unless more accurate analytical techniques are available, there-



Comparison of results obtained on analysis of duplicate samples of milled and un-milled plant material
METAL CONTENT IN P.P.M. OF UN-MILLED PLANT (OVEN-DRY WEIGHT BASIS)
METAL CONTENT IN P.P.M. OF MILLED PLANT (OVEN-DRY WEIGHT BASIS)
1000
100
10
1
0·1
0·1
1
10
100
1000
1500
KEY
COPPER
LEAD
ZINC
Limits of 25% analytical error

FIG. 49.

fore, it would seem that milling the plant samples will not materially affect the results.

(4). Oven-drying

The samples were dried for one hour at 105°C immediately prior to ashing. Owing to the hygroscopic nature of the material, the samples must be rapidly weighed after drying.

(5). Choice of crucible

Loss of metal by retention on silica crucibles has been reported by Gorsuch, (1959). To test this possibility, four samples were ashed in silica crucibles, and the results compared with duplicate samples ashed in platinum basins, (Table 34). No appreciable differences between the duplicates are evident. It is therefore concluded that loss of metal by retention on the material of the crucible is unlikely to be a serious problem at the temperature used in the present study, (430°C, see below).

(6). Dry-ashing method

Ashing of large samples was carried out in Translucent Vitreosil crucibles, (150 ml.), and smaller samples in 25 ml. crucibles of the same material. Lids were not used, as a better ash results if air is allowed to pass freely over the material.

The weight of material ashed was in part dependent on the part of the plant to be analysed. Generally a quantity between 4 and 12 gm. gave sufficient ash for the 0.1 gm.

Table 34: Tephrosia sp. nov., (Dugald River MMC/DMJP No. 5). Comparison of Results of Analyses of Duplicate Samples Ashed with Silica or Platinum Crucibles. Milled, dry-ashed material.

No.	Locality	Type of Crucible	Part of Plant	% Ash	ppm of Ash			Cu/Zn Ratio	ppm of oven-dry material			ppm of soil (4-6 ins)			Cu/Zn Ratio	Rock Type
					Cu	Pb	Zn		Cu	Pb	Zn	Cu	Pb	Zn		
40/83	350S/350W	Silica	Stems	2.98	110	240	24000	0.004	3.27	7.15	715					Lode/Footwall junction
		Platinum	"	3.20	85	320	22000	0.004	2.72	10.24	704					
40/102	3520N/800W	Silica	"	3.00	135	15	24000	0.005	4,05	0.45	720	70	1200	2100	0,033	Alluvium on Lode
		Platinum	"	3.08	120	20	22000	0.005	3.70	0.62	677					
40/146	18700N/2100E	Silica	"	5.36	75	<10	170	0.44	4.02	<1	9.11	120	<5	18	6.66	Sheet wash cover
		Platinum	"	4.84	75	<10	180	0.42	3.63	<1	8.71					
40/147	18700N/2300E	Silica	"	4.14	70	<10	80	0.87	2.89	<1	3.31	30	<5	24	1.25	Sheet wash cover
		Platinum	"	4.22	70	<10	80	0.87	2.95	<1	3.38					

sample weight of ash used in the analyses, but smaller quantities were sometimes necessitated, e.g. flowers and fruits. The samples were weighed in a previously-weighed crucible, and ashed overnight, (or for a period of eight hours whichever was convenient), at 430°C in an electric muffle furnace. Before placing the material in the furnace the temperature was first allowed to fall to about 390°C; otherwise there was a danger of the sample igniting. During the ashing the door of the furnace was left slightly raised to allow a current of air to pass over the material.

On completion, the crucibles were cooled in a dessicator and then weighed. The 0.1 gm. sample required for the analyses was then rapidly weighed out, and transferred to a test tube to await analysis.

(7). Wet-ashing method

Although dry-ashing has been popular in biogeochemistry many workers in the biological field have used wet-digestion with mixtures of strong acids for the destruction of organic matter. Twenty-four duplicate samples were therefore ashed by the method described below, and the results compared with those obtained from dry-ashing, (Fig. 50).

The technique is based on Method 2A of Gorsuch, (1960). Five to seven gm. of accurately-weighed oven-dried milled material was placed in a 500 ml. Erlenmeyer flask, and 25 ml. of concentrated nitric acid, (Analar), added. The mixture was placed on a hot plate in a fume cupboard and

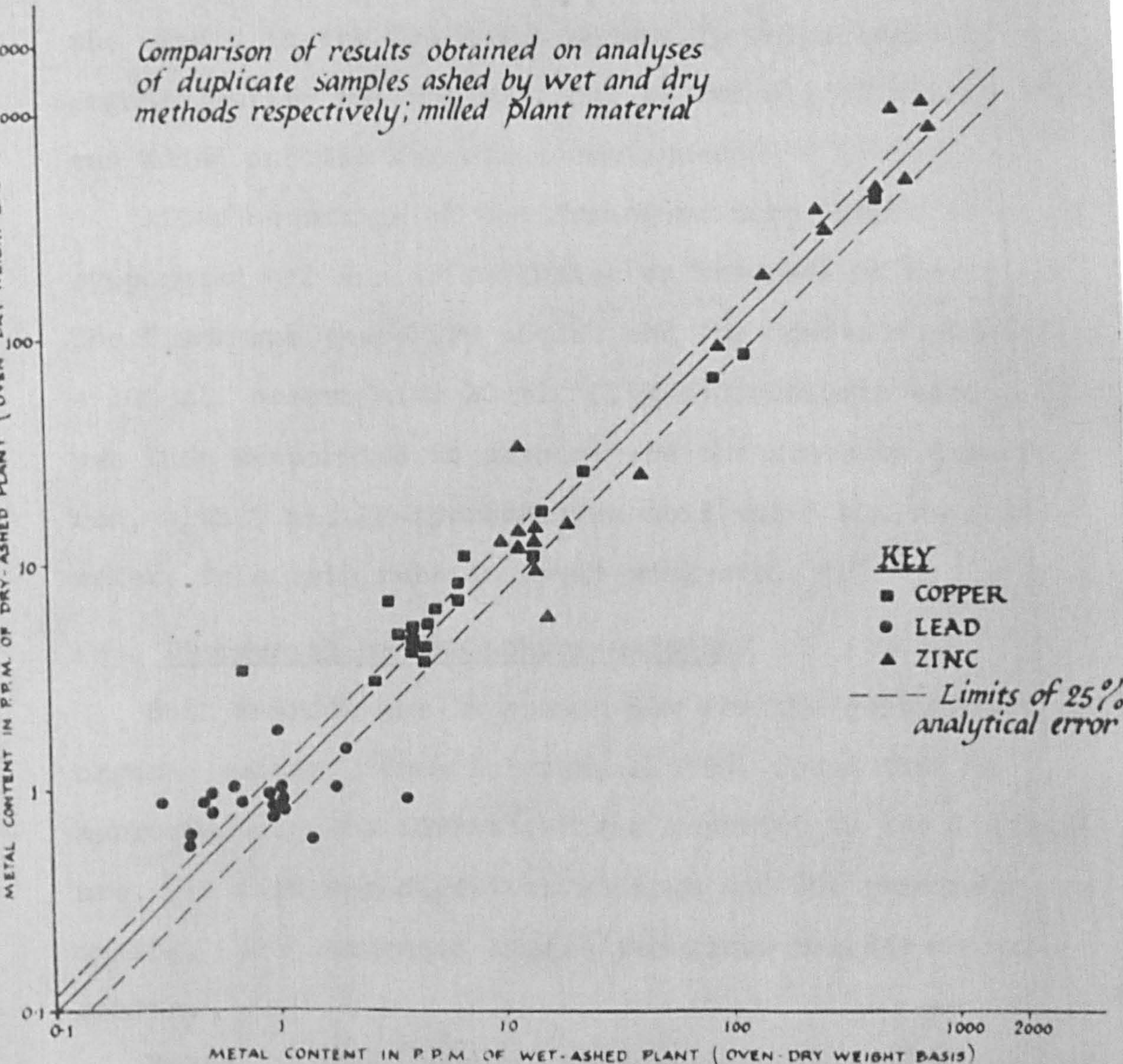

Comparison of results obtained on analyses of duplicate samples ashed by wet and dry methods respectively; milled plant material
KEY
COPPER
LEAD
ZINC
Limits of 25% analytical error
METAL CONTENT IN P.P.M. OF DRY-ASHED PLANT (OVEN DRY WEIGHT BASIS)
METAL CONTENT IN P.P.M. OF WET-ASHED PLANT (OVEN-DRY WEIGHT BASIS)
0·1
1
10
100
1000
2000

FIG. 50.

the temperature slowly raised to the boiling point. After one hour the flask was cooled, 10 ml. perchloric acid added, and the mixture again brought slowly to boiling. Heating was continued for up to two hours till the emission of white fumes had ceased. During this latter stage the liquid in the flask was generally colourless; if any organic matter was present, one to two ml. of nitric acid was added and the digestion continued.

After cessation of the fuming no more liquid is being eveporated off due to refluxing on the neck of the flask. The flask was therefore cooled and the contents rinsed into a 100 ml. beaker with 10 ml. 0.5M-hydrochloric acid. This was then evaporated to dryness and the contents transferred, with 5 ml. 1M-hydrochloric acid and 5 ml. de-ionised water, to a test tube to await analysis.

(8). Discussion on the ashing methods

Both methods are in common use for the destruction of organic matter. Thus Gorsuch, (1959), found that of approximately 250 investigations reported in the literature, 51% used wet-digestion methods and the remainder dry-ashing. The commonest single technique was direct dry-ashing.

Piper, (1950), reports that the siliceous residue left after digestion of the ash with hydrochloric acid, (as was done in the present study), always retains small amounts of the constituents, particularly of the trace elements.

He therefore advises wet-digestion with a sulphuric, nitric and perchloric acid mixture. However, Gorsuch, (ibid), states that the use of sulphuric acid may cause difficulties by the formation of lead sulphate. For this reason it was omitted from the acid mixture used in the present investigation. Moreover, the acid, being manufactured by the Lead Chamber process, is likely to contain appreciable amounts of this metal.

The graphed results of the duplicate samples ashed by the two methods, (Fig. 50), indicates no pronounced variation between the values obtained from dry and wet ashing. The various advantages and disadvantages of the two methods may therefore be summarised as follows.

Dry-ashing

Advantages

Contamination from acids is not a problem.

The method requires little attention.

The quantity of ash remaining after ashing could be weighed and hence the results expressed both as metal content of the ash and of the oven-dry material.

Disadvantages

Metal may be retained on the silica of the crucible.

Metal may be retained in the siliceous residue left after digestion in hydrochloric acid.

Metal loss may occur if the temperature exceeds 450°C.

Wet-ashing

Advantages

Loss by retention on the sides of the vessel is not a problem.

As the temperature cannot exceed the boiling point of the acid mixture used, loss by volatisation cannot occur.

Metal loss by retention on the complex silicates left after digestion with hydrochloric acid is not a problem

Disadvantages

Contamination from acids may occur.

Results can only be expressed as metal content of the ~~ash.~~ oven-dry material.

Due to frothing in the early stages of the digestion, large amounts of material cannot be safely dealt with.

The method requires almost constant attention.

Explosions may occur due to decomposition of perchloric acid.

B. Determination of copper, lead and zinc in plant ash

The following analytical procedures are based on those currently in use at the Geochemical Prospecting Research Centre, Royal School of Mines, London, for analysis of soil, sediment and rock samples.

(1). Sample attack

(i). Fuse 0.5 gm. of potassium bisulphate with 0.1 gm. of ash in a Pyrex test tube, (16 x 150 mm.)

(ii). Leach with 5 ml. of IM-hydrochloric acid.

(iii). Add 5 ml. of de-ionised water and mix.

The leachate resulting from the above procedures provides aliquots for the various colorimetric determinations described below.

(2). <u>Determination of copper, (after GPRC Tech. Comm. No. 23).</u>

(a). <u>Reagents</u>

(i). <u>0.02% 2,2'-diquinolyl solution</u> : dissolve 40 mg. in 200 ml. of amyl alcohol.

(ii). <u>Buffer solution</u> : dissolve 200 gm. of sodium acetate, (trihydrate), 100 gm. of potassium sodium tartrate, (tetrahydrate), and 20 gm. of hydroxylamine hydrochloride in water and dilute to one litre. Extract with 0.01% dithizone until free from copper and then remove the excess of dithizone by extraction with carbon tetrachloride. The pH of the buffer should be 6.05 ± 0.15 and the optimum pH range of the fina[l] acqueous phase 4.0 - 9.0.

(iii). <u>Standard copper solutions</u> : 100 µg. of copper per ml. - dissolve 200 mg. of cupric sulphate, (pentahydrate), in 0.5 M-hydrochloric acid and dilute to 500 ml. with this acid.

10 µg. of copper per ml. - dilute 10 ml. of the 100 µg. per ml. solution to 100 ml. with 0.5

M-hydrochloric acid.

1 µg. of copper per ml. - dilute 10 ml. of the 10 µg. per ml. solution to 100 ml. with 0.5 M-hydrochloric acid.

(b). Preparation of standards:

To 20 test tubes calibrated at 10 and 12 ml., and each containing 10 ml. of buffer solution, add respectively 0, 0.2, 0.4, 0.6, 0.8, 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10, 12, 14, 16, 18, 20 µg. of copper. Dilute to 12 ml. with 0.5M-hydrochloric acid, add 2 ml. of diquinolyl solution, cork the tube and shake vigorously for 30 sec.

(c). Determination of copper in unknowns

(i). Pipette a 2 ml. aliquot of leachate into 10 ml. of buffer solution contained in an 18 x 180 mm. test tube, previously calibrated at 10 and 12 ml.

(ii). Add 2 ml. of 0.02% 2.2'-diquinolyl solution.

(iii). Cork the tube and shake vigorously for 30 sec.

(iv). Compare with standards.

(v). If above top standard, add another 2 ml. of diquinolyl solution and shake for a further 30 sec.

(vi). If still above top standard, repeat with a sample aliquot of 0.1 ml. and dilute to 12 ml.

with 0.5 M-hydrochloric acid at stage (v).

Copper in ppm = 50 x (µg, of copper in matching standard) x (ml. of solvent phase) / (ml. of sample aliquot).

Remarks

(i). The range covered is 5 - 2000 ppm with an aliquot of 2 ml. and 1000 - 20,000 ppm with an aliquot of 0.1 ml.

(ii). Results may be obtained within ± 25% at the 95% confidence level over the range 5 - 20,000 ppm.

(3). Determination of lead, (after GPRC Tech. Comm. No. 16

(a). Reagents

(i). 0.0008% dithizone in benzene : make up daily from an 0.01% stock solution and store in a vacuum flask.

(ii). 0.04% thymol blue : dissolve 40 mg. of the sodium salt in 100 ml. of water.

(iii). Buffer solution : dissolve 120 gm. of tri-ammonium citrate and 20 gm. of hydro-xylamine hydrochloride in about 800 ml. of water. Add 5 ml. of 0.04% thymol blue solution followed by ammonia solution (S.G. 0.880) until the colour of the indicator changes from yellow to a distinct blue. Add 18 gm. of potassium cyanide and dilute to 1 litre with water. Extract with 0.01% dithizone in carbon tetrachloride until free from lead, and remove the excess of dithizone by extraction with chloroform. The pH of the buffer solution should be between 9.5 - 9.8.

(iv). Standard lead solution : 100 µg. of lead per ml. - dissolve 80 mg. of lead nitrate in 0.5 M-hydrochloric acid and dilute to 500 ml. with this acid.

5 µg. of lead per ml. - dilute 5 ml. of the 100 µg. per ml. solution to 100 ml. with 0.5 M-hydrochloric acid.

(b). Preparation of standards:

To each of 12 test tubes (19 x 150 mm.) calibrated at 10 and 12 ml., and each containing 10 ml. of buffer solution, add respectively 0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 5.0, 6.0, 7.0 µg. of lead. Dilute to 12 ml. with 0.5 M-hydrochloric acid and add 5 ml. of 0.0008% dithizone in benzene. Cork the tubes and shake vigorously for 15 sec. Keep in a cool dark place when not in use.

(c). Determination of lead in unknowns

(i). Pipette a 2 ml. aliquot of leachate into 10 ml. of buffer solution, contained in a 19 x 150 mm. Pyrex test tube previously calibrated at 10 and

12 ml.

(ii). Add 5 ml. of 0.0008% dithizone solution.

(iii). Cork tubes and shake vigorously for 30 sec.

(iv). Compare with standards. Use smaller aliquot if above top standard. When using an aliquot of less than 1 ml., the aqueous phase should be made up to 12 ml. with 0.5 M-hydrochloric acid.

Lead in ppm = 50 x (µg. of lead in matching standard).

Remarks

(i). The range covered is 10 - 350 ppm as described above, but may be extended to 7000 ppm by using an aliquot of 0.1 ml.

(ii). Results may be obtained within ± 25% at the 95% confidence level over the range 10 - 7000 ppm.

(4). Determination of zinc, (after GPRC Tech. Comm. No. 30)

(a). Reagents

(i). 0.001% dithizone in benzene : make up daily from an 0.01% stock solution and store in a vacuum flask.

(ii). Buffer solution : dissolve 500 gm. of sodium acetate, 5 gm. of sodium fluoride and 125 gm. of sodium thiosulphate in about 1500 ml. of water. Add 15 ml. of acetic acid and extract with 0.01% dithizone in carbon tetrachloride until free from zinc. Remove the excess of dithizone by extraction with carbon tetrachloride and dilute the aqueous phase to 2 litres with water. The pH of the buffer solution should be 6.0 ± 0.15.

(iii). Standard zinc solution : 100 µg. of zinc per ml. - dissolve 220 mg. of zinc sulphate heptahydrate in 0.5 M-hydrochloric acid and dilute to 500 ml. with this acid.

5 µg. of zinc per ml. - dilute 5 ml. of the 100 µg. per ml. solution to 100 ml. with 0.5 M-hydrochloric acid.

(b). Preparation of standards:

To 9 test tubes each containing 5 ml. of buffer solution, add respectively 0, 0.25, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5 µg. of zinc. Add 5 ml. of 0.001% dithizone, cork the tubes and shake vigorously for 1 min. Keep in a cool dark place when not in use.

(c). Determination of zinc unknowns

(i). Pipette a 1 ml. aliquot of leachate into 5 ml. of buffer solution in a test tube, (18 x 180 mm.), calibrated at 5 ml.

(ii). Add 5 ml. of 0.001% dithizone solution.

(iii). Cork tubes and shake vigorously for 1 min.

(iv). Compare with standards. If above top standard use smaller aliquot.

Zinc in ppm = (100 x μg. of zinc in matching standard).

<u>Remarks</u>

(i). A range of 5 - 350 ppm is covered, but it may be extended up to 3500 ppm by using an aliquot of 0.1 ml.

(ii). Results can be obtained within $\pm$ 25% at the 95% confidence level over the range 5 - 3500 ppm.

APPENDIX C

Comparative lists of the species occurring in the plant associations, communities and assemblages of the Dugald River and Bulman Areas

Table 35

Comparative List of the Species occurring in the Plant Associations, Communities and Assemblages of the Dugald River Area

(1). Eucalyptus brevifolia - Triodia pungens association
(2). Eucalyptus brevifolia - E. dichromophloia - Triodia pungens association
(3). Eucalyptus brevifolia - Acacia chisholmi - Cleome viscosa association
(4). Eucalyptus argillacea - E. terminalis - Acacia chisholmi - Triodia pungens association
(5). Eucalyptus argillacea - E. terminalis - Carissa lanceolata - Sporobolus australasicus association
(6). Acacia cambagei association
(7). Astrebla pectinata - Iseilema macrathera association
(8). Melaleuca leucadendron - Eucalyptus camaldunensis - Tristania grandiflora community
(9). Tephrosia sp. nov. (Dugald R. No. 5) - Polycarpaea glabra - Eriachne mucronata - Bulbostylis barbata assemblage

d :- dominant species o :- occasional species

c :- common species r :- rare species

TREES.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Eucalyptus brevifolia	d	d	d	o	o	o		r
Eucalyptus argillacea	o			d	d	o		c

TREES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Eucalyptus terminalis		r	o	d	d	o		o
Eucalyptus dichromophloia	o	d						
Acacia cambagei					o	d	o	
Eucalyptus camaldunensis								d
Melaleuca viridiflora								d
Tristania grandiflora								d
Eucalyptus papuana	o		r	o	c	o		
Terminalia aridicola	c	c	c					c
Eucalyptus pruinosa	o				o	o		
Atalaya hemiglauca	r			o	c	o		
Hakea suberea				o	o			o
Acacia coriacea	o							
Eremophila mitchelli					o	c		
Bauhinia carronii					o	c		c
Bauhinia cunninghamii						o		o
Acacia bidwilli	r			o	o	o		
Acacia hemignosta				r	o			
Maytenus cunninghamii	o			o	o			o
Grevillea mimosoides				o				
Eucalyptus aspera	r							
Eucalyptus setosa		r						
Grevillea striata					r			r
Acacia mangium								r
Hakea arborescens								r
Eucalyptus tectifica				r				
Clerodendron tomentosum	r							

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8
TREES								
Clerodendron floribundum				r				
Brachychiton australe			r					
SHRUBS								
Acacia chisholmi	o		d	d	c	o		c
Carissa lanceolata	o			r	d	o		c
Cassia desolata					c	c		
Eremophila latrobei				r	o	c	r	
Acacia phlebocarpa		c						[illegible]
Securinega virosa								c
Melaleuca bracteata								o
Tephrosia sp. nov. (No. 5)	o			o	r			
Myoporum montanum	o			o	o			
Acacia retivenia	o							
Cassia pruinosa	r				r			
Cassia venusta	r							r
Cassia absus								r
Santalum lanceolatum	r			r				
Cassia oligophylla					r			
Acacia lysiphloia								r
Acacia galioides	r							
Dodonaea lanceolata				r				
Corchorus sidoides				r				
GRASSES								
Triodia pungens	d	d	c	d	c	o		c
Sporobolus australasicus	c	r	r	c	d	c		c
Enneapogon polyphyllus	o	r	r	c	c	o		o

GRASSES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(
Aristida browniana	o	r	r	o	c	o		c	[illegible]
Eulalia fulva	c	c	o	o	o	r		r	
Eriachne pulchella	c	c	o	o	o			r	
Paspadilium rarum	o	o	o	r	c	c		r	
Eriachne mucronata	o	o	o	r	r	o			[illegible]
Enneapogon oblongus	o	o	o	o					
Tragus australianus	r				c	r			
Schizachyrium sp. (No. 73)	c	c	o						
Chrysopogon fallax					c			c	
Aristida pruinosa					o			o	
Brachyachne convergens					o			o	
Dactyloctenium radulans					o				
Perotis rara					c			o	
Heteropogon contortus					o			o	
Triodia longiceps				o	o				r
Iseilema macrathera							d		
Astrebla pectinata							d		
Eragrostis leptocarpa				o				o	
Eragrostis japonica							c		
Chloris acicularis					c		o	o	
Eriachne obtusa								o	
SEDGES									
Bulbostylis barbata	o				c				d
Fimbristylis sp. (No. 279)				r					c
Cyperus iria								o	

HERBS	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Cleome viscosa	c	c	d	c	c	c		c
Tribulus terrestris	r			c	o			o
Tribulus pentandrus	c	c	o	c	o			
Gomphrena brownii	o	o	o	o	c	o		c
Ptilotus fusiformis var. gracilis	o	r	r	c	o			
Boerhavia diffusa	r	r	o	c	o			o
Heliotropium tenuifolium	c	o	o	c	o			r
Portulaca intraterranea	o	r	r	o	c	r		o
Amaranthus interruptus	o	r	r	r				
Breweria media	r				c			o
Polycarpaea corymbosa	o	r	r		r			
Polycarpaea glabra	r							r
Indigofera linifolia	r			r	r			r
Euphorbia australis				r	r			
Euphorbia ughligiana	r			r	r			r
Scaevola densivestita				o	o			
Corchorus pumilio	r			r				
Evolvulus alsinoides var. villosicalyx					o			r
Notoxylinon australe				r				
Abutilodon andrewsianum				r				
Malvastrum spicatum				r				r
Solanum sp. (No. 21)					o			
Solanum ellipticum	r				o			
Borreria australiana	r				r			

<u>HERBS</u>	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(
Borreria breviflora				o					
Crotalaria aff. novae hollandiae								o	
Ptilotus spicatus							c		
Andrachne decaisnei				o	r				
Indigofera colutea								r	
Indigofera enneaphylla	r				r			r	
Indigofera hirsuta								r	
Heliotropium sp. (No. 23)					d				
Tephrosia eriocarpa	o								
Tephrosia rosea				r					
Tephrosia sp. (No. 192)	r			r					
Tephrosia brachychidon var. longifolia	r			r					
Crotalaria trifoliastrum	r				r		r		
Polymeria ambigua					r				
Ptilotus clementii				o	r				
Ptilotus obovatus					r				o
Neptunia gracilis					r		r	r	
Melhania incana					r				
Corchorus tridens	r				r				
Goodenia vilmorinae					r				
Trichodesma zeylanica					r				
Euphorbia sp. aff.schultzii	r								
Citrullus vulgaris								r	
Pterocaulon verbascifolium					o				

HERBS	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(
Breweria pannosa					o				
Trianthema triquetra					o			r	
Chenopodium auricomum					o				
Ocimum sanctum							o		
Sida acuta							o		
Hibiscus trionum							o		
Hibiscus ficulneus							o		
Desmodium muelleri							o		
Ipomoea lonchophylla							o		
Plumbago zeylanica								o	
Anisomeles salviaefolia								o	
Alternanthera denticulata								o	
Melothria maderaspatana								o	

Table 36

Comparative List of the Species occurring in the Plant Associations, Communities and Assemblages of the Bulman Area

(1). Erythrophleum chlorostachys - Eucalyptus spp. - Gardenia megasperma - Chrysopogon pallidus - Andropogoneae indet. (Bulman No. 156) association

(2). Cochlospermum fraseri - Acacia pallida - Vetiveria elongata - Heteropogon contortus community

(3). Gardenia megasperma - Erythrophleum chlorostachys - Vetiveria elongata - Chrysopogon pallidus community

(4). Eucalyptus tectifica - E. confertiflora - Hakea arborescens - Heteropogon contortus - Andropogoneae indet. (Bulman No. 156) - Iseilema vaginiflorum association

(5). Sorghum sp. (Bulman No. 184) - Chionachne cyathopoda - Iseilema vaginiflorum, with Terminalia platyphylla and Tristania grandiflora - association

(6). Pandanus sp. - Timonius timon - Heteropogon contortus - Flaveria australasica community

(7). Imperata cylindrica var. major - Flaveria australasica community

(8). Pipturus argenteus - Melaleuca viridiflora community

(9). Polycarpaea synandra var. gracilis - Gomphrena canescens - Aristida browniana - Tephrosia aff. polyzyga - Fimbristylis schultzii assemblage d :- dominant species   o :- occasional species

c :- common species   r :- rare species

<u>TREES</u>	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Erythrophleum chlorostachys	d	o	d						
Gardenia megasperma	d	o	d	c					
Eucalyptus tectifica	d			d					
Eucalyptus ferruginea	d								
Eucalyptus tetrodonta	d								
Eucalyptus jenseni	d								
Eucalyptus confertiflora				d					
Pandanus sp. (No. 206)					c	d			
Tristania grandiflora					c	c			
Hakea arborescens		o	o	d					
Terminalia platyphylla				c	c	o			
Acacia pallida		d	c	c	o	r			
Cochlospermum fraseri		d	o						
Timonius timon						d	o		
Melaleuca viridiflora				o	o	o		d	
Pipturus argenteus							o	d	
Eucalyptus papuana			r	o	o				
Eucalyptus patellaris		r		c					
Terminalia pterocarya	c								
Brachychiton gregorii	r	o	o	r					
Eucalyptus grandifolia	o								
Eucalyptus bigalerita	o			o					
Ficus opposita var. micrantha				o		o			

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(
TREES									
Grevillea dimidiata		o	o						
Grevillea heliosperma	o								
Bauhinia cunninghamii				r					
Alstonia actinophylla			o		r				
Eucalytus setosa	o								
Ficus racemosa							r		
Eucalyptus pruinosa			r						
SHRUBS									
Petalostigma quadriloculare	c								
Tephrosia aff. polyzyga	o		o						d
Tephrosia sp. (No. 118)	o								
Grewia retusifolia	r				o				
GRASSES									
Chrysopogon pallidus	d		d	o					o
Andropogoneae indet. (No.156)	d		c	d	c				
Heteropogon contortus	o	d	o	d	c	d			
Vetiveria elongata		d	d						o
Indeterminate grass (No. 123)	d	o	o	r					
Andropogoneae indet.(No.135)	c								
Iseilema vaginiflorum				d	d				
Sorghum sp. (No. 184)					d	c			
Chionachne cyathopoda					d				
Imperata cylindrica var. major						r	d		
Heteropogon triticeus	o	r	c						o

GRASSES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(
Aristida browniana	o	o	o	o					
Plectrachne pungens	o								
Panicum sp. (No. 136)	o		r						
Eriachne sp. (No. 144)	o		r						
Schizachyrium sp. (No. 126)	r			o					
Eriachne ciliata	r								
Themeda australis	r								
Eragrostis japonica				r		o			
Elytrophorus spicatus				r					
Eriachne obtusa		o							
SEDGES									
Fimbristylis schultzii									c
Bulbostylis barbata	o	o	o						
Fimbristylis cardiocarpa	r	r							
Fimbristylis phaeoleuca				r					
HERBS									
Flaveria australasica					o	d	d		
Sesbania aculeata					c	o			
Polycarpaea spirostylis	c								
Polycarpaea synandra var. gracilis				r					d
Polycarpaea corymbosa	r	o							
Galactia muelleri	o		c						o
Euphorbia sp. (No. 127)		o	c	r					
Gomphrena canescens	o								c
Trianthema rhynchocalyptra	o								

HERBS.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(
Indigofera linifolia	r	o	o						
Andrachne decaisnei				r					
Corchorus acutangulus				r					
Boerhavia diffusa		o		r					
Heliotropium ventricosum	r	r							
Desmodium filiforme	r								
Helicteres cana	r								
Uraria cylindracea	o								
Ipomoea polymorpha	r								
Pterocaulon sphacelatum					r				
Pterocaulon verbascifolium		o							
Ptilotus fusiformis		o							
Melothria maperaspatana						o		o	
Cleome viscosa		o							